6 AGUIJAN

6.1 Introduction

Aguijan, also called Aguiguan, is a small, uninhabited island of the Commonwealth of the Northern Mariana Islands (CNMI) and is located 8 km southwest of Tinian at 17°36′ N, 145°50′ E. The highest elevation of this low-lying island is only 57 m. Oriented northeast–southwest, Aguijan has a land area of 7.01 km^2 and an elongated shape that is ~ 4.8 km long and 1.6 km wide (Fig. 6.1a). Like the adjacent islands of Tinian and Saipan, Aguijan is composed of a series of uplifted carbonate terraces overlying an older volcanic structure and surrounded by steep sea cliffs (Fig. 6.1b).

Figure 6.1a. Satellite image of Aguijan (IKONOS Carterra Geo Data, 2003).

Figure 6.1b. Aguijan is surrounded by steep cliffs, as seen from a small boat during MARAMP 2007. *NOAA photo*

6.1.1 History and Demographics

Archaeological evidence of Chamorro culture on Aguijan has been found in the form of pottery shards and latte sets, and an old village was located on the top of this island. However, it is not certain how much of the time Aguijan was permanently inhabited or whether it was mainly used for temporary fishing camps (Rogers 1995; Rainbird 2004). Aguijan has significant historical importance as the stage of the last battle between Spain and the Chamorro of the Mariana Archipelago. In 1695, Chamorro on Tinian sent women and children to Aguijan for safety, subsequently leaving for Aguijan themselves to join them while Spain was defeating Chamorro on Saipan. Surviving Chamorro were taken to Guam for resettlement (Rogers 1995). After the period of control by Spain, Aguijan, like Tinian and Saipan, came under control by Germany, until the period of Japanese administration that followed World War I (WWI). During WWII, the Japanese maintained a garrison on Aguijan, which was surrendered to the U.S. Coast Guard in 1944. Since 1945, this island has remained uninhabited (Cruz et al. 2000). Currently, Aguijan is administered by the municipality of Tinian. Tinian residents visit periodically for hunting, although access to Aguijan is limited because of the steep cliffs that surround it (Cruz et al. 2000). South of Aguijan, a small islet called Naftan Rock has been used by the U.S. Navy for bombing practice, which has resulted in the presence of unexploded ordnance in surrounding waters (Starmer 2005).

6.1.2 Geography

Aguijan, like the neighboring islands of Guam, Rota, Tinian, and Saipan, is composed of a series of coralline limestone terraces that lie on top of a volcanic core. These terraces are very flat and separated by steep slopes (Fig. 6.1.2a). No beaches are found around Aguijan, which is instead surrounded by sea cliffs.

Although Aguijan is completely vegetated, human activities and feral ungulates have affected its natural vegetation (Fig. 6.1.2b). Extensive areas of level land were cleared on Aguijan for Japanese sugarcane plantations, and *Casuarina* trees were planted as windbreaks on the upper terraces (Mueller-Dombois and Fosberg 1998). The areas that weren't cleared have retained native limestone forest, similar in composition to forests on Tinian but dominated by a relatively small number of species (Esselstyn et al. 2003).

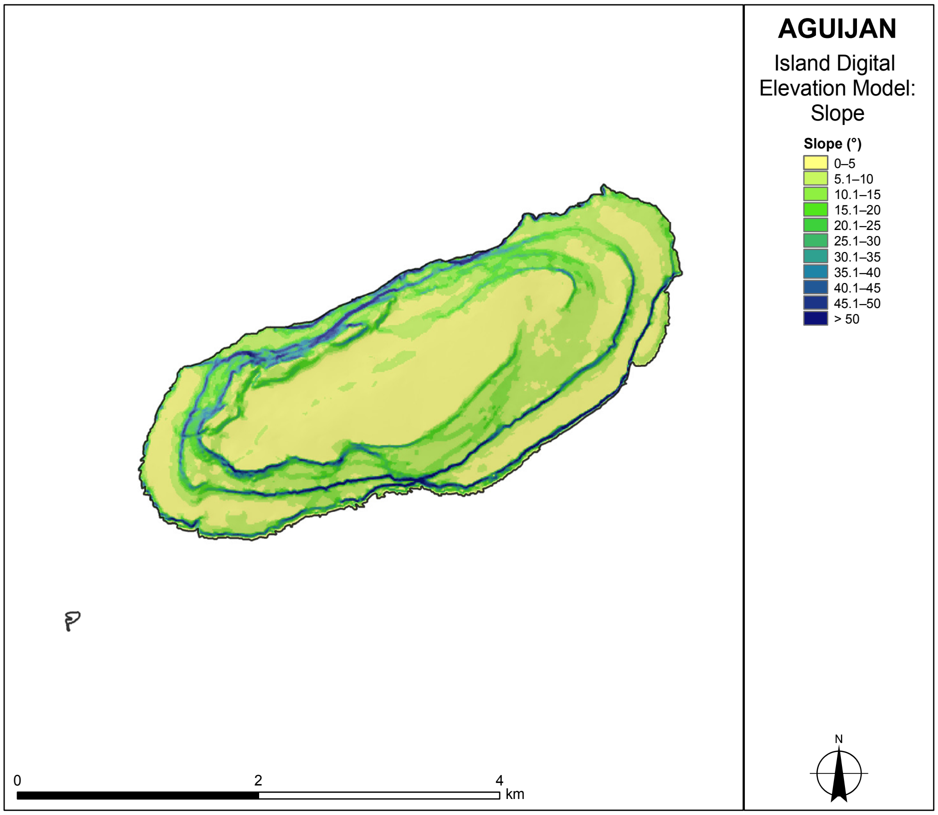


Figure 6.1.2a. Slope map using the digital elevation model (grid cell size: 10 m) for Aguijan.

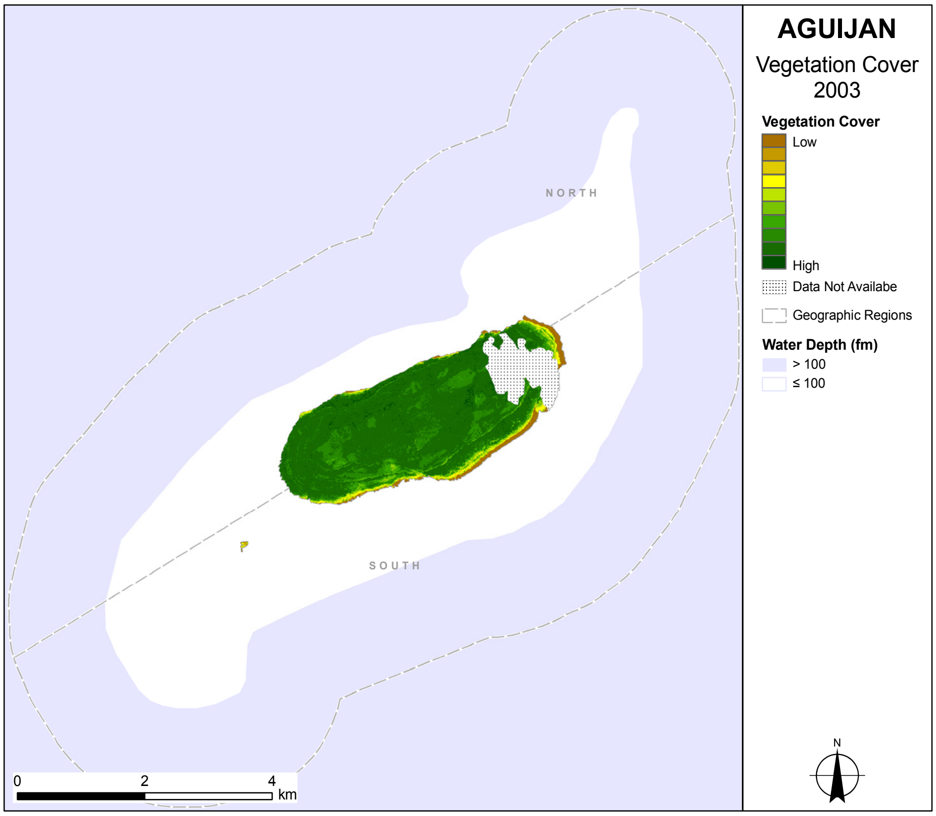


Figure 6.1.2b. Vegetation cover on Aguijan, derived using the Normalized Difference Vegetation Index from a satellite image (grid cell size: 4 m; IKONOS Carterra Geo Data, 2001). Hatched lines display areas where data are not available because cloud cover obscures the satellite image.

6.1.3 Environmental Issues on Aguijan

The main environmental issues of concern on Aguijan are the effects of feral ungulates on native flora and the spread of the invasive weed *Lantana camara*. Feral goats have affected severely this island's native forests. An eradication program conducted in 1990 was only partially successful (Campbell and Donlan 2005), and the goat population on Aguijan in 1998 remained at an estimated 1500 animals (Atkinson and Atkinson 2000). Goats affect this island's native forest by causing severe erosion and removing the understory, which is becoming dominated by the aggressively invasive weed *Lantana camara* (Esselstyn et al. 2003).

Maintenance of native forest is of key importance for the support of associated fauna. Aguijan supports a number of native bird species, including ~ 10% of the archipelago-wide population of the Mariana grey swiftlet (*Aerodramus vanikorensis bartschi*), also known as the Guam swiftlet and listed both Federally as endangered and locally as threatened or endangered; Micronesian megapode (*Megapodius laperouse*), also listed Federally as endangered and locally as threatened or endangered; and golden white-eye (*Cleptornis marchei*), also found on Guam (U.S. Fish and Wildlife Service; Berger et al. 2005; Cruz et al. 2000; Esselstyn et al. 2003).

Aguijan has a small population of the Mariana fruit bat (*Pteropus mariannus mariannus*), which is listed Federally as endangered and locally as threatened or endangered (U.S. Fish and Wildlife Service; Berger et al. 2005). Estimates made in 2002 put this bat population at 30–50 individuals, considerably lower than estimates of 150–200 from surveys in 2000, a drop that could be a result of periodic poaching (Esselstyn et al. 2003).

Another issue for Aguijan is the proposed development of ecotourism (Esselstyn et al. 2003). Ecotourism providers would need to develop landing areas or piers to allow safe access to Aguijan, since access to this island is very limited because of steep sea cliffs.

6.2 Survey Effort

Biological, physical, and chemical observations collected under the Mariana Archipelago Reef Assessment and Monitoring Program (MARAMP) have documented the conditions and processes influencing coral reef ecosystems around the island of Aguijan since 2003. The spatial reach and time frame of these survey efforts are discussed in this section. Different areas around this island often are exposed to different environmental conditions. To aid discussions of spatial patterns of ecological and oceanographic observations that appear throughout this chapter, 2 geographic regions around Aguijan are delineated in Figure 6.2a; wave exposure and breaks in survey locations were considered when defining these geographic regions. This figure also displays the locations of the Rapid Ecological Assessment (REA) surveys, towed-diver surveys, and towed optical assessment device (TOAD) surveys conducted around Aguijan. Potential reef habitat around this island is represented by a 100-fm contour shown in white on this map.

Benthic habitat mapping data were collected around Aguijan using a combination of acoustic and optical survey methods. MARAMP benthic habitat mapping surveys conducted around Aguijan, Tinian, Tatsumi Reef, Saipan, and Marpi Bank with multibeam sonar covered a total area of 213.4 km^2 in 2003 and 1800 km^2 in 2007. Optical validation and habitat characterization were completed using towed-diver and TOAD surveys that documented live-hard-coral cover, sand cover, and habitat complexity. The results of these efforts are discussed in Section 6.3: "Benthic Habitat Mapping and Characterization."

Information on the condition, abundance, diversity, and distribution of biological communities around Aguijan was collected using REA, towed-diver, and TOAD surveys. The results of these surveys are reported in Sections 6.5–6.8: "Corals and Coral Disease," "Algae and Algal Disease," "Benthic Macroinvertebrates," and "Reef Fishes." The numbers of surveys conducted during MARAMP 2003, 2005, and 2007 are presented in Table 6.2a, along with their mean depths and total areas or length.

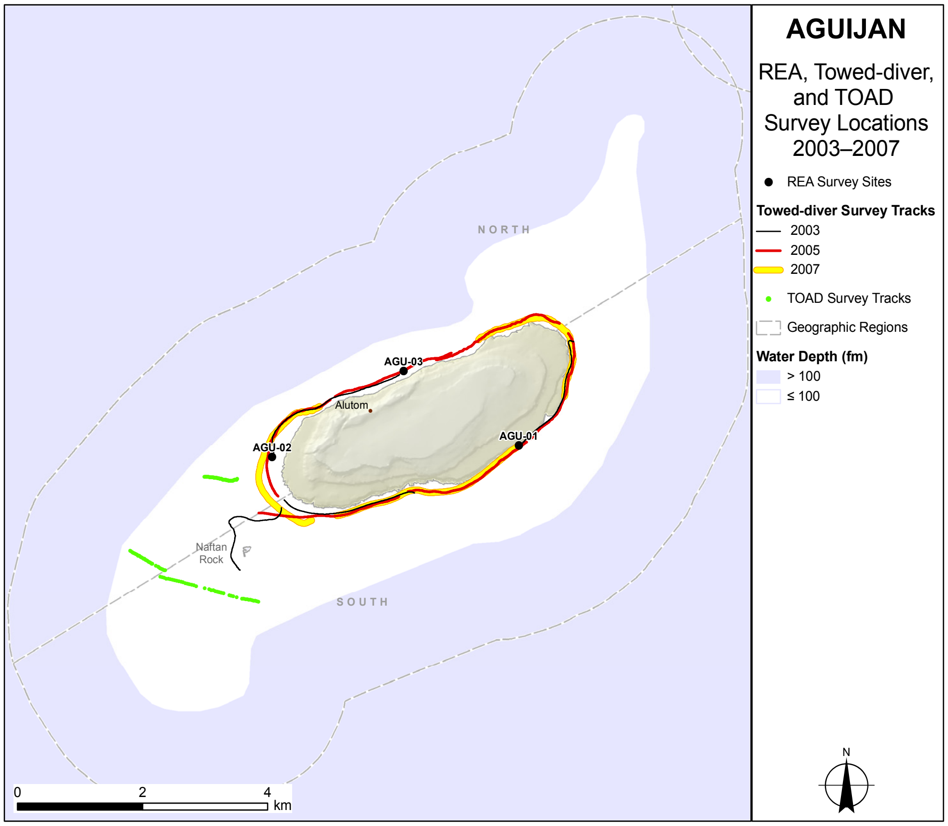


Figure 6.2a. Locations of the REA, towed-diver, and TOAD benthic surveys conducted around Aguijan during MARAMP 2003, 2005, and 2007. To aid discussion of spatial patterns, this map delineates 2 geographic regions: north and south.

Table 6.2a. Numbers, mean depths (m), total areas (ha), and total length (km) of REA, towed-diver, and TOAD surveys conducted around Aguijan during MARAMP 2003, 2005, and 2007. REA survey information is provided for both fish and benthic surveys, the latter of which includes surveys of corals, algae, and macroinvertebrates.

Survey Type	Survey Detail	Year		
REA		**2003**	**2005**	**2007**
Fish	Number of Surveys	2	3	1
	Mean Depth (m)	14 (SD 1.4)	13.8 (SD 1)	13.5
Benthic	Number of Surveys	2	3	2
	Mean Depth (m)	14 (SD 1.4)	13.8 (SD 1)	13.3 (SD 0.4)
Towed Diver		**2003**	**2005**	**2007**
	Number of Surveys	4	6	3
	Total Survey Area (ha)	8.7	12.6	8.5
	Mean Depth (m)	13.6 (SD 0.5)	17.1 (SD 1.7)	15.2 (SD 0.6)
TOAD		**2003**		
	Number of Surveys	3		
	Total Length (km)	2.71		

Spatial and temporal observations of key oceanographic and water-quality parameters influencing reef conditions around Aguijan were collected using (1) subsurface temperature recorders (STR) designed for long-term observations of high-frequency variability of temperature, (2) closely spaced conductivity, temperature, and depth (CTD) profiles of the vertical structure of water properties, and (3) discrete water samples for nutrient and chlorophyll-*a* analyses. CTD casts were conducted during MARAMP 2003, 2005, and 2007, and water sampling was performed during MARAMP 2005 and 2007. Results for some casts and water samples are not presented in this report because either the data were redundant or erroneous or no data were produced (see Chapter 2: "Methods and Operational Background," Section 2.3: "Oceanography and Water Quality"). A summary of deployed instruments and collection activities is provided in Table 6.2b, and results are discussed in Section: 6.4: "Oceanography and Water Quality."

Table 6.2b. Numbers of STRs deployed, shallow-water and deepwater CTD casts performed, and water samples collected around Aguijan during MARAMP 2003, 2005, and 2007. Shallow-water CTD casts and water samples were conducted from the surface to a 30-m depth, and deepwater casts were conducted to a 500-m depth. Additional deepwater CTD cast information is presented in Chapter 3: "Archipelagic Comparisons."

Observation Type	Year						
Instruments	2003	2005		2007		2009	Lost
	Deployed	Retrieved	Deployed	Retrieved	Deployed	Retrieved	
STR	1	–	1	1	1	1	1
CTD Casts	2003	2005		2007			Total
Shallow-water Casts	12	21		19			52
Deepwater Casts	–	4		1			5
Water Samples		2005		2007			Total
		3		3			6

Towed-diver Surveys: Depths

Figures 6.2b and c illustrate the locations and depths of towed-diver-survey tracks around Aguijan and should be referenced when further examining results of towed-diver surveys from MARAMP 2003, 2005, and 2007.

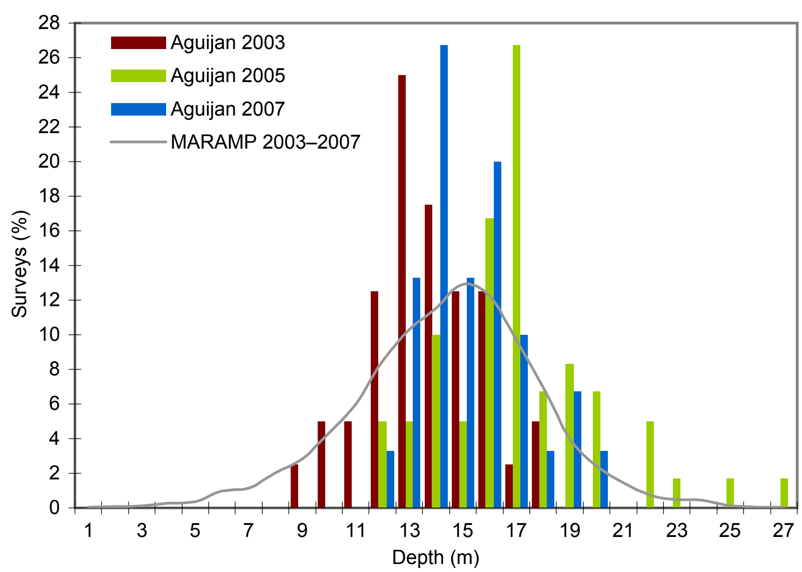


Figure 6.2b. Depth histogram plotted from mean depths of 5-min segments of towed-diver surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Mean segment depths were derived from 5-s depth recordings. Segments for which no depth was recorded were excluded. The grey line represents average depth distribution for all towed-diver surveys conducted around the Mariana Archipelago during MARAMP 2003, 2005, and 2007.

During MARAMP 2003, 4 towed-diver surveys were conducted along parts of the forereef slopes of Aguijan (Figs. 6.2b and c top panel). The mean depth of all survey segments was 13.6 m (SD 2.6), and the mean depths of individual surveys ranged from 13.3 m (SD 2.8) to 14.4 m (SD 2.3).

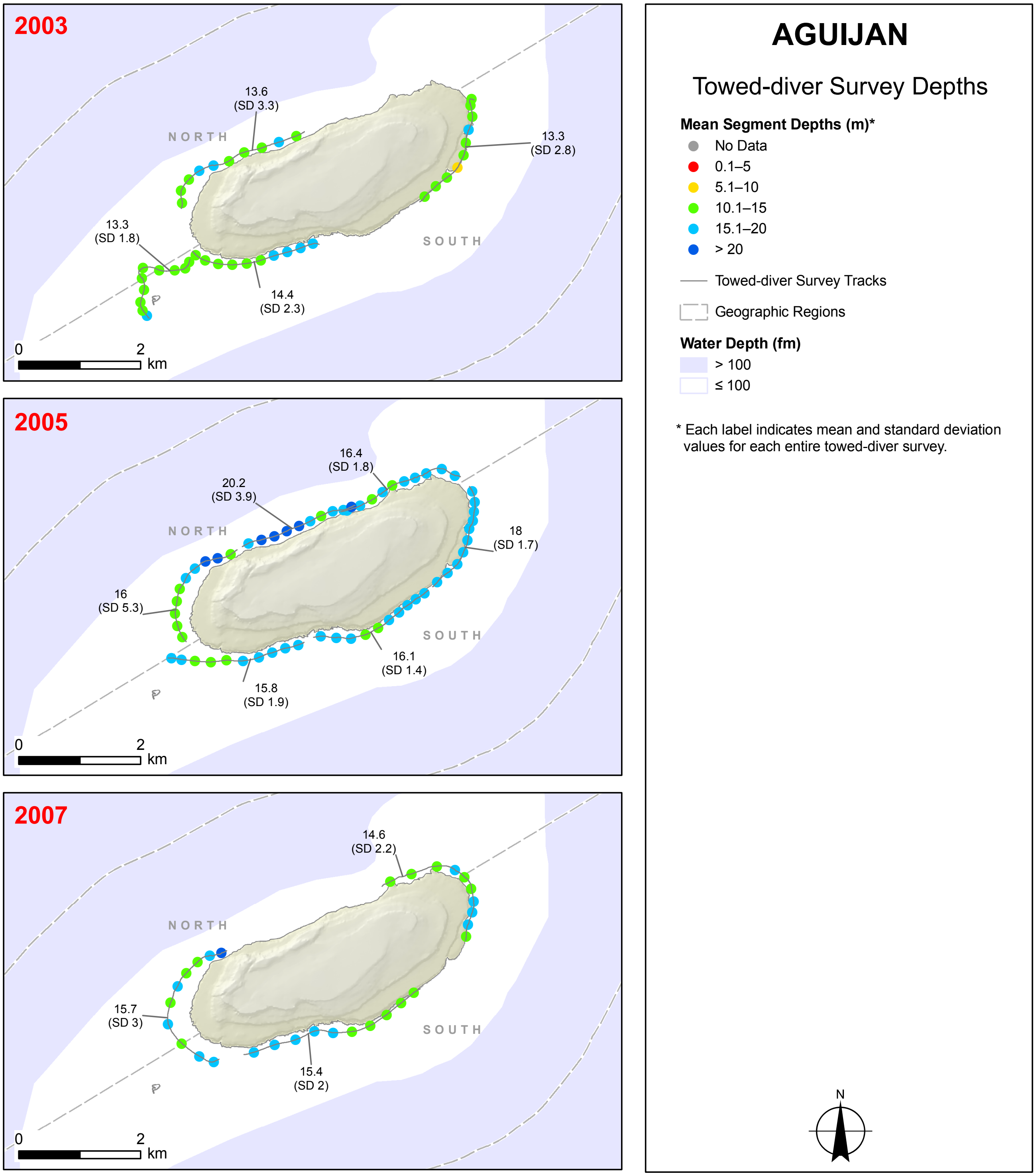


Figure 6.2c. Depths and tracks of towed-diver surveys conducted on forereef slopes around Aguijan during MARAMP 2003, 2005, and 2007. Towed-diver-survey tracks are color coded by mean depth for each 5-min segment. A black-text label shows the mean depth (and standard deviation) for each entire towed-diver survey. Each depth represents the depth of the benthic towboard during each survey; towboards are maintained nominally 1 m above the benthic substrate.

During MARAMP 2005, 6 towed-diver surveys were conducted along the forereef slopes of Aguijan (Figs. 6.2b and c middle panel). The mean depth of all survey segments was 17.1 m (SD 3.4), and the mean depths of individual surveys ranged from 15.8 m (SD 1.9) to 20.2 m (SD 3.9).

During MARAMP 2007, 3 towed-diver surveys were conducted along parts of the forereef slopes of Aguijan (Figs. 6.2b and c bottom panel). The mean depth of all survey segments was 15.2 m (SD 2.5), and the mean depths of individual surveys ranged from 14.6 m (SD 2.2) to 15.7 m (SD 3).

6.3 Benthic Habitat Mapping and Characterization

Benthic habitat mapping and characterization surveys around the island of Aguijan were conducted during MARAMP 2003, 2005, and 2007 using acoustic multibeam sonar, underwater video and still imagery, and towed-diver observations. Acoustic multibeam sonar mapping provided bathymetric and backscatter data products over the depth range of ~ 200–1500 m. Optical validation and benthic characterization, via diver observations and both video and still underwater imagery, were performed using towed-diver surveys and TOAD deployments conducted at depths of ~ 15–100 m.

6.3.1 Acoustic Mapping

Multibeam acoustic bathymetry and backscatter imagery (Fig. 6.3.1a) collected by the Coral Reef Ecosystem Division around Aguijan, Tinian, Tatsumi Reef, Saipan, and Marpi Bank in 2007 encompassed an area of 2013.4 km^2. Multibeam data acquisition was limited to the single pass completed by the NOAA Ship *Hi`ialakai* around this island in 2007 cover-

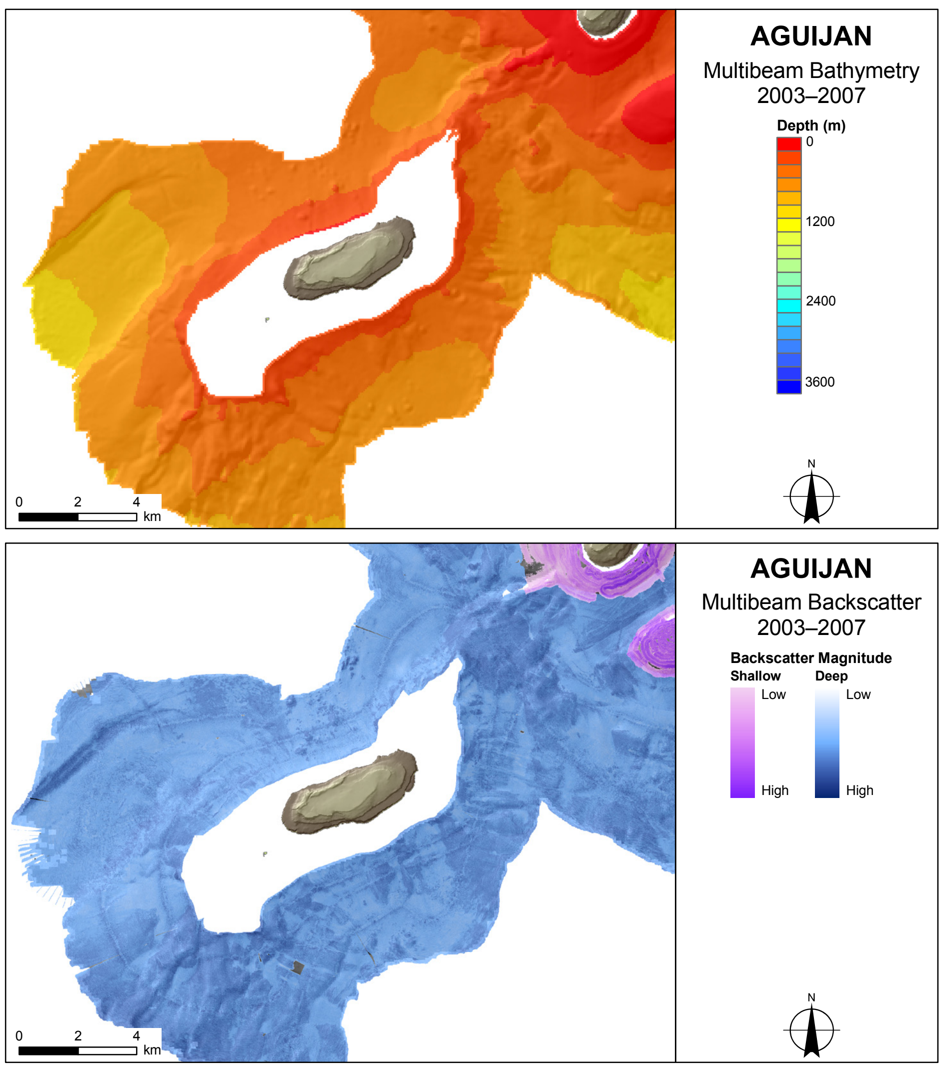


Figure 6.3.1a. Gridded (*top*) multibeam bathymetry (grid cell size: 60 m) and (*bottom*) backscatter (grid cell size: 5 m) collected around Aguijan during MARAMP 2007 at depths of 200–1500 m. Backscatter data (shown in blue) were collected using a 30-kHz Kongsberg EM 300 sonar. Light shades of blue represent low-intensity backscatter and may indicate acoustically absorbent substrates, such as unconsolidated sediment. Dark shades represent high-intensity backscatter and may indicate consolidated hard-bottom or coral substrates.

ing depths of ~ 200 to ~ 1000 m. Additional data were acquired by the *Hi'ialakai* to depths of ~ 1500 m during transits between Aguijan and adjacent islands.

Multibeam bathymetry acquired during MARAMP 2007 reveals a sloping bank around Aguijan (Fig. 6.3.1a, top panel). East of Aguijan, the flanks of the bank descend to a depth of 400 m within ~ 2 km of this island's coast. North of Aguijan, a broad submerged ridge connects the bank to Tinian at a depth of ~ 380 m. Northeast of Aguijan, bathymetry data suggest a series of narrow, parallel ridges, the tops of which gradually deepen to depths of ~ 650 m. South of this island, bathymetry show rugged topography with 2 steep-sided ridges. West of Aguijan, a major bathymetric feature is an ~ 3-km-wide depression that reaches a depth of 1000 m at the edge of the multibeam survey area.

The limited amount of backscatter data acquired around Aguijan show some variability. Higher backscatter values, relative to other surveyed areas, suggest that harder substrates may be present along the tops of the ridges, described above, northeast, north, and south of Aguijan (Fig. 6.3.1a, bottom panel). Multibeam data collected around Aguijan also reveal that flatter areas of the seabed are generally associated with lower backscatter values, suggesting that these areas may be characterized by softer sediments.

6.3.2 Optical Validation

During MARAMP 2003, 3 TOAD optical-validation surveys were conducted at Aguijan at depths of ~ 15–100 m (for survey locations, see Figure 6.2a in Section 6.2: "Survey Effort"). Subsequent analysis of video acquired from these surveys provided estimates of the percentages of sand cover and live-hard-coral cover (Fig. 6.3.3a).

Covering a distance of 30 km at depths of 9–27 m, 13 towed-diver optical-validation surveys were conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. At 5-min intervals within each survey, divers recorded percentages of sand cover and live-hard-coral cover and habitat complexity using a 6-level categorical scale from low to very high.

6.3.3 Habitat Characterization

Both towed-diver observations and analyses of TOAD video footage showed low sand cover at most of the areas surveyed at Aguijan (< 20% in most areas), suggesting that the seabed in these areas was predominantly composed of hard substrates (Fig. 6.3.3a, top panel). The distribution of sand cover also showed an east–west gradient, with sand cover higher to the west of Aguijan than to the east. The greatest level of sand cover, recorded during towed-diver surveys within a range of 20.1%–50%, was observed in an area south of this island, and the seabed there was characterized by sand with patch reefs. Analyses of video footage from TOAD surveys suggest that 100% sand cover occurred in slightly deeper (50–100 m) waters surveyed to the west of Naftan Rock (for place-names and their locations, see Figure 6.2a in Section 6.2: "Survey Effort"). Otherwise, sand cover was predominantly low for the areas surveyed with the TOAD, with a few smaller patches of sand recorded to the south of Naftan Rock. No general conclusions about the distribution of sand in shallow versus deeper waters can be drawn from these data, since the area of seabed surveyed by the TOAD is much less than the area covered by towed-diver surveys.

Observations from towed-diver surveys conducted at depths of 9–27 m showed that habitat complexity generally was higher on the north side of this island than on the south side (Fig. 6.3.3a, middle panel). Distribution of live corals at Aguijan from on towed-diver surveys suggests a similar pattern: higher live coral cover was observed on the north side, where habitat complexity was also highest, and lower live coral cover was seen on the less complex south side (Fig. 6.3.3a, bottom panel). Around northern Aguijan, live coral cover was generally 10.1%–40% and divers observed a mixture of carbonate pavement, reef slopes, and spur-and-groove habitat. Around southern Aguijan, live coral cover was generally < 10%, with estimates higher on the southwest coast, where coral cover of 10.1%–20% was recorded. Observed habitats included hard pavement, boulders, and rubble. No live corals were observed in the analyses of TOAD video footage.

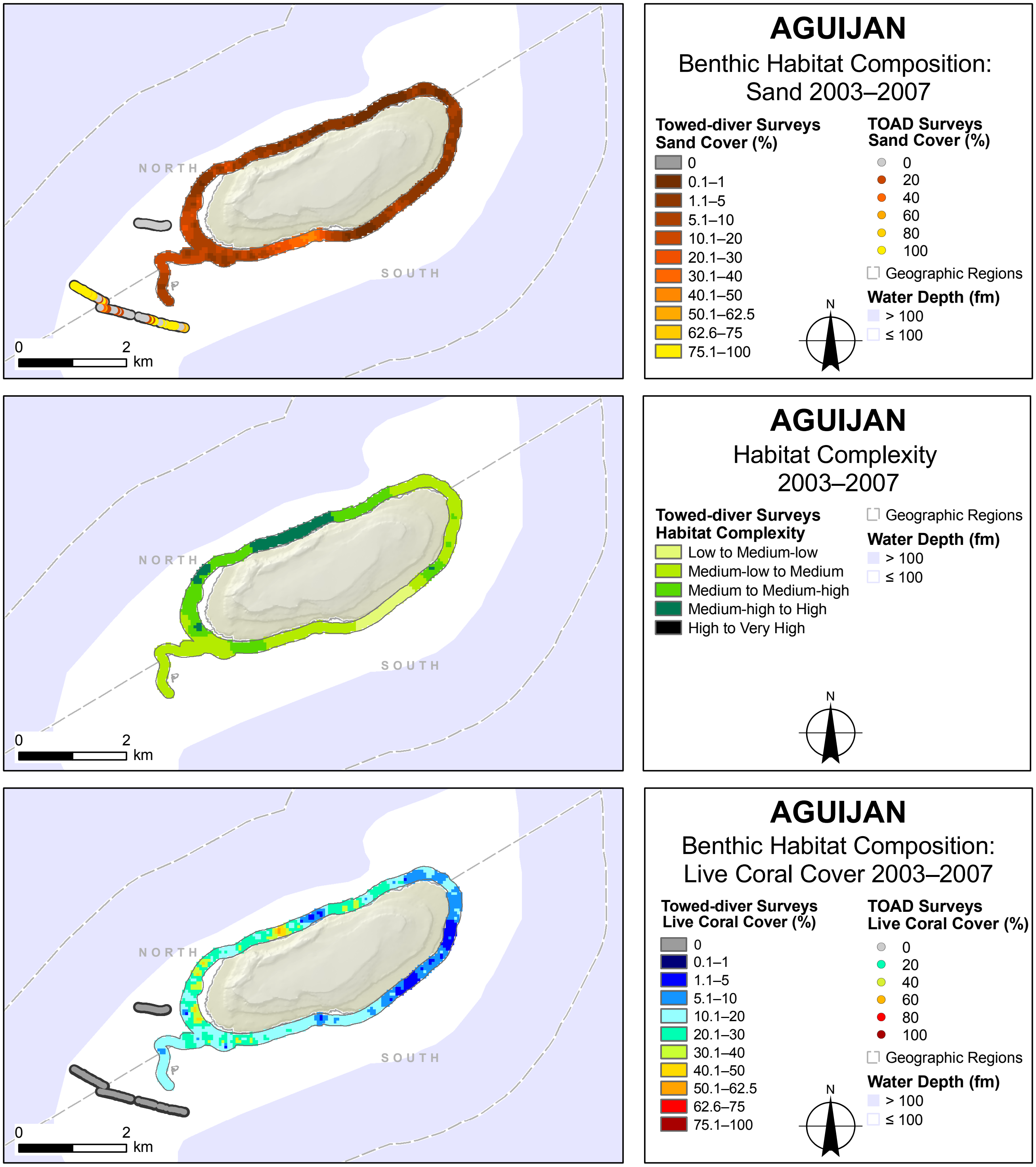


Figure 6.3.3a. Observations of (*top*) sand cover (%), (*middle*) benthic habitat complexity, and (*bottom*) cover (%) of live hard corals from towed-diver surveys of forereef habitat conducted and analysis of TOAD video collected around Aguijan during MARAMP 2003, 2005, and 2007.

6.4 Oceanography and Water Quality

6.4.1 Hydrographic Data

2003 Spatial Surveys

During MARAMP 2003, 12 shallow-water conductivity, temperature, and depth (CTD) casts were conducted in nearshore waters around the island of Aguijan on September 17. Temperature, salinity, and density values from these casts varied both spatially and vertically around Aguijan. Spatial comparisons of water properties at a depth of 10 m suggest low variability around Aguijan with recorded temperature differences up to 0.4°C. The coldest temperature (29.52°C) in the north region (cast 1) coincided with the highest salinity (34.35 psu) and greatest density (21.4 kg m^{-3}) values (Fig. 6.4.1a). Vertical comparisons of CTD profiles reveal water properties with a broad range in temperature (1.1°C) values and a moderate range in salinity (0.3 psu) values (Fig. 6.4.1b). The greatest range in vertical water properties was recorded on the west side of the south region. The high stratification of the water column in this area may have been caused by the combined effects of solar heating on surface waters and topography-related tidal mixing below the depth of 15 m.

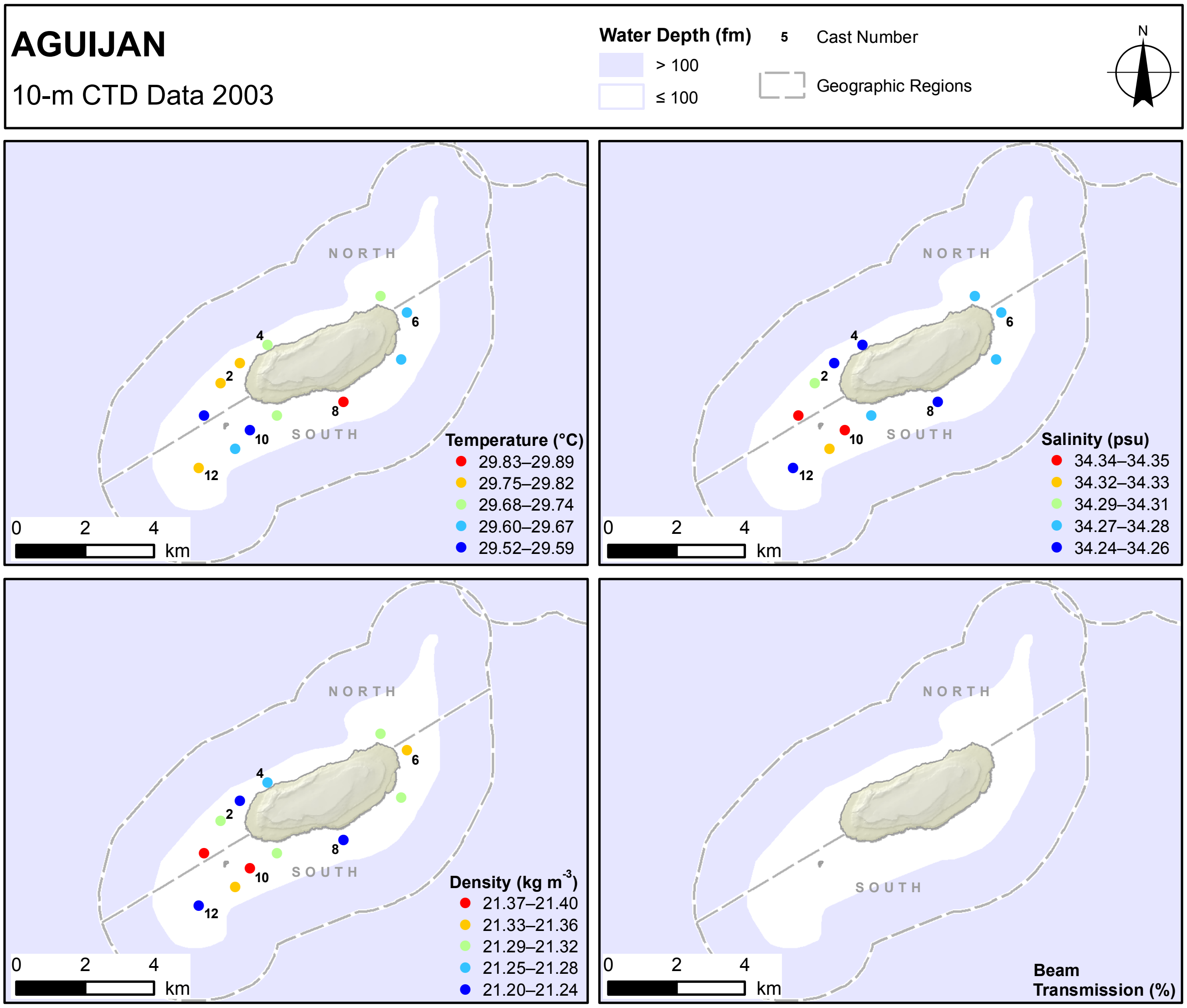


Figure 6.4.1a. Values of (*top left*) water temperature, (*top right*) salinity, and (*bottom left*) density at a 10-m depth from shallow-water CTD casts around Aguijan on September 17 during MARAMP 2003.

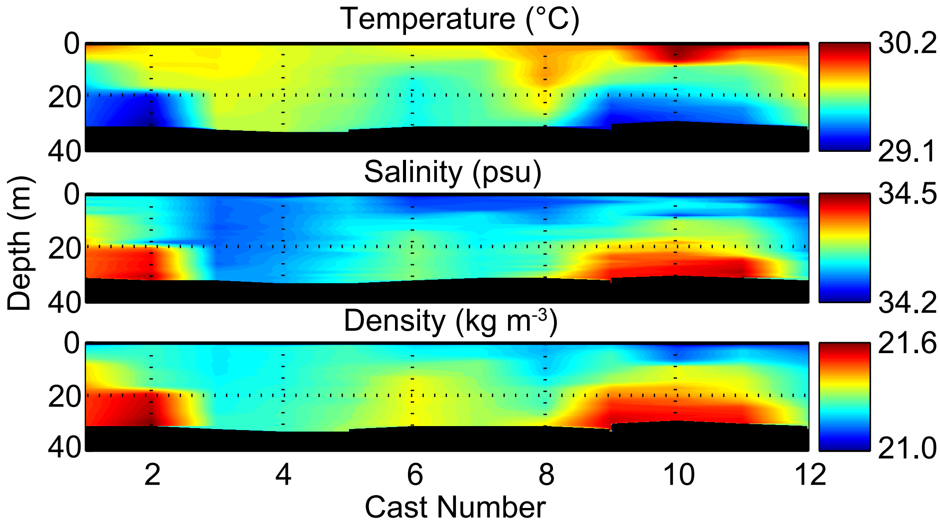


Figure 6.4.1b. Shallow-water CTD cast profiles to a 30-m depth around Aguijan on September 17 during MARAMP 2003, including temperature (°C), salinity (psu), and density (kg m^{-3}). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–12 in a clockwise direction around Aguijan. For cast locations and numbers around this island in 2003, see Figure 6.4.1a.

2005 Spatial Surveys

During MARAMP 2005, shallow-water CTD casts were conducted in nearshore waters around Aguijan over the period of September 27–28. Temperature, salinity, density, and beam transmission values from 20 of these casts varied both spatially and vertically around Aguijan. Spatial comparisons of water properties at a depth of 10 m show no clear spatial pattern around this island; however, a moderate range in temperature (0.8°C) was recorded (Fig. 6.4.1c). Vertical comparisons of CTD profiles reveal a series (casts 10–14, 17) of cold-water intrusions (Fig. 6.4.1d). Variation of salinity (0.2 psu) and density (1.1 kg m^{-3}) values occurred concurrently with these drops in temperature (1°C) values, suggesting enhanced mixing with deeper waters relative to other areas around this island. Beam transmission was generally high (~ 94%) at all cast locations.

Water samples were collected in conjunction with shallow-water CTD casts at 3 select locations at Aguijan in 2005 to assess water-quality conditions. The following ranges of measured parameters were recorded: chlorophyll-*a* (Chl-*a*), 0.15–0.97 µg L^{-1}; total nitrogen (TN), 0.29–0.34 µM; nitrate (NO_3^-), 0.27–0.32 µM; nitrite (NO_2^-), 0.023–0.025. µM; phosphate (PO_4^{3-}), 0.013–0.016 µM; and silicate [$Si(OH)_4$], 0.73–0.85 µM. All parameters measured around Aguijan were similar at the east end of the south and north regions (Fig. 6.4.1e). In contrast, one location southwest of this island in the south region showed dissimilar water properties. Chl-*a* concentration was greater, total nitrogen and nitrate concentrations were lower, and nitrite, phosphate, and silicate concentrations were similar at this location relative to the other cast locations at Aguijan.

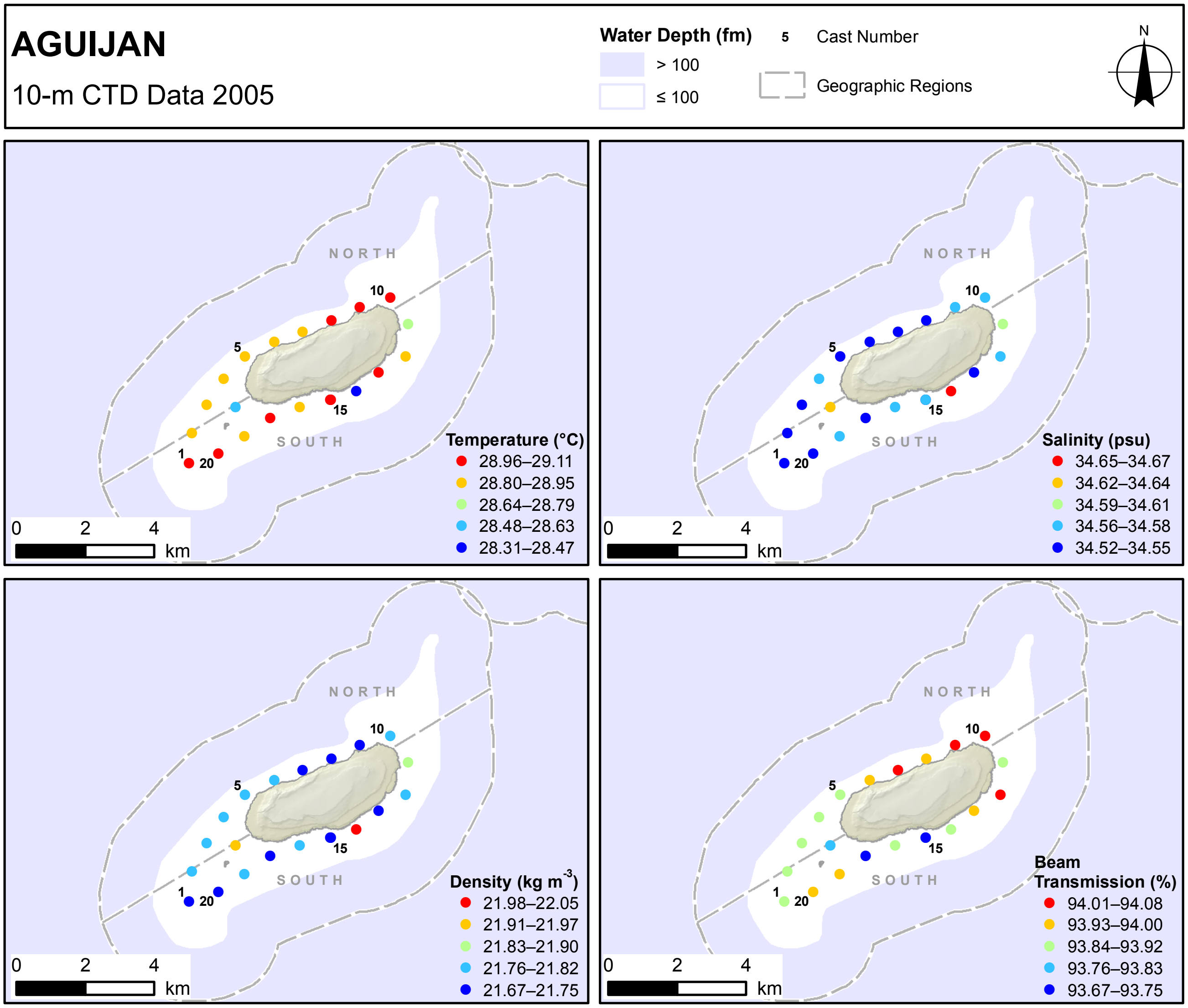


Figure 6.4.1c. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, and (*bottom right*) beam transmission at a 10-m depth from shallow-water CTD casts around Aguijan on September 27–28 during MARAMP 2005.

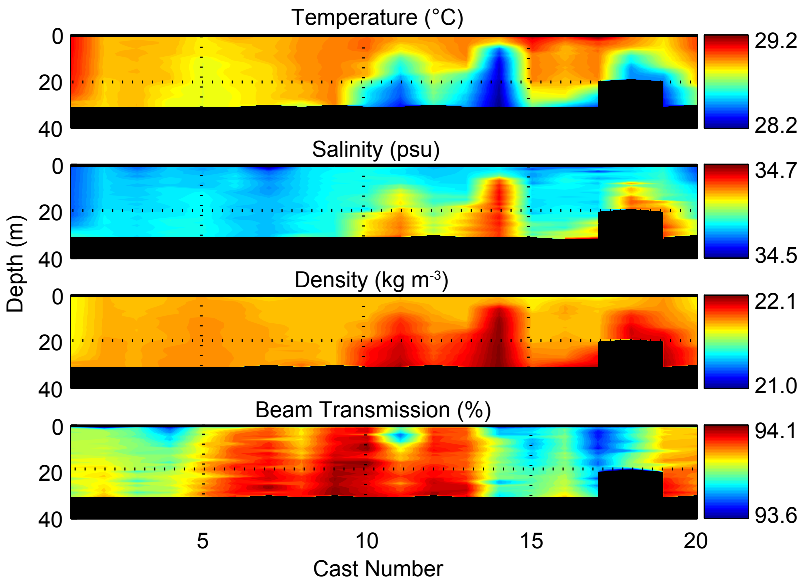


Figure 6.4.1d. Shallow-water CTD cast profiles to a 30-m depth around Aguijan on September 27–28 during MARAMP 2005, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–20 in a clockwise direction around Aguijan. For cast locations and numbers around this island in 2005, see Figure 6.4.1c.

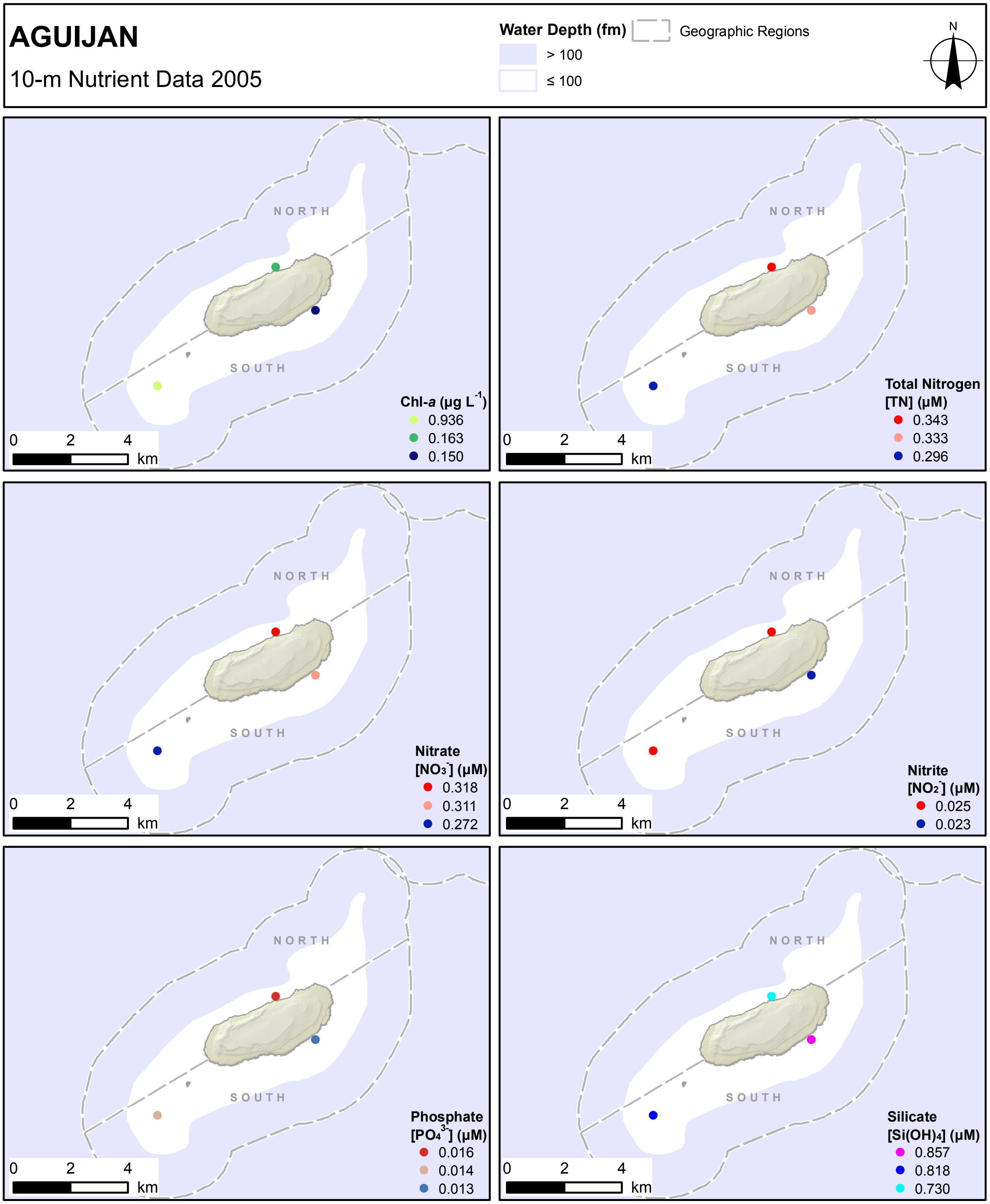


Figure 6.4.1e. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected at Aguijan on September 27–28 during MARAMP 2005.

2007 Spatial Surveys

During MARAMP 2007, shallow-water CTD casts were conducted in nearshore waters around Aguijan on May 18. Temperature, salinity, density, and beam transmission values from 18 of these casts varied both spatially and vertically around Aguijan. Spatial comparisons of water properties at a depth of 10 m show no clear spatial pattern around this island; the coldest (cast 16) and warmest (casts 1, 12) temperatures were recorded in the south region within 2 km of each other (Fig. 6.4.1f). Vertical comparisons of CTD profiles (Fig. 6.4.1g) reveal a large range in temperature (1°C) values and a series of disparate cold-water intrusions to the west, north, and south of this island (casts 1, 9, 16). Moderate variation of salinity (0.2 psu) and density (0.5 kg m^{-3}) values occurred concurrently with these drops in temperature values, suggesting enhanced mixing with deeper waters or localized upwelling relative to other areas of this island. Beam transmission was generally high (~ 94%) at all cast locations; all temperature, salinity, and water-clarity data show little, if any, sign of terrestrial runoff.

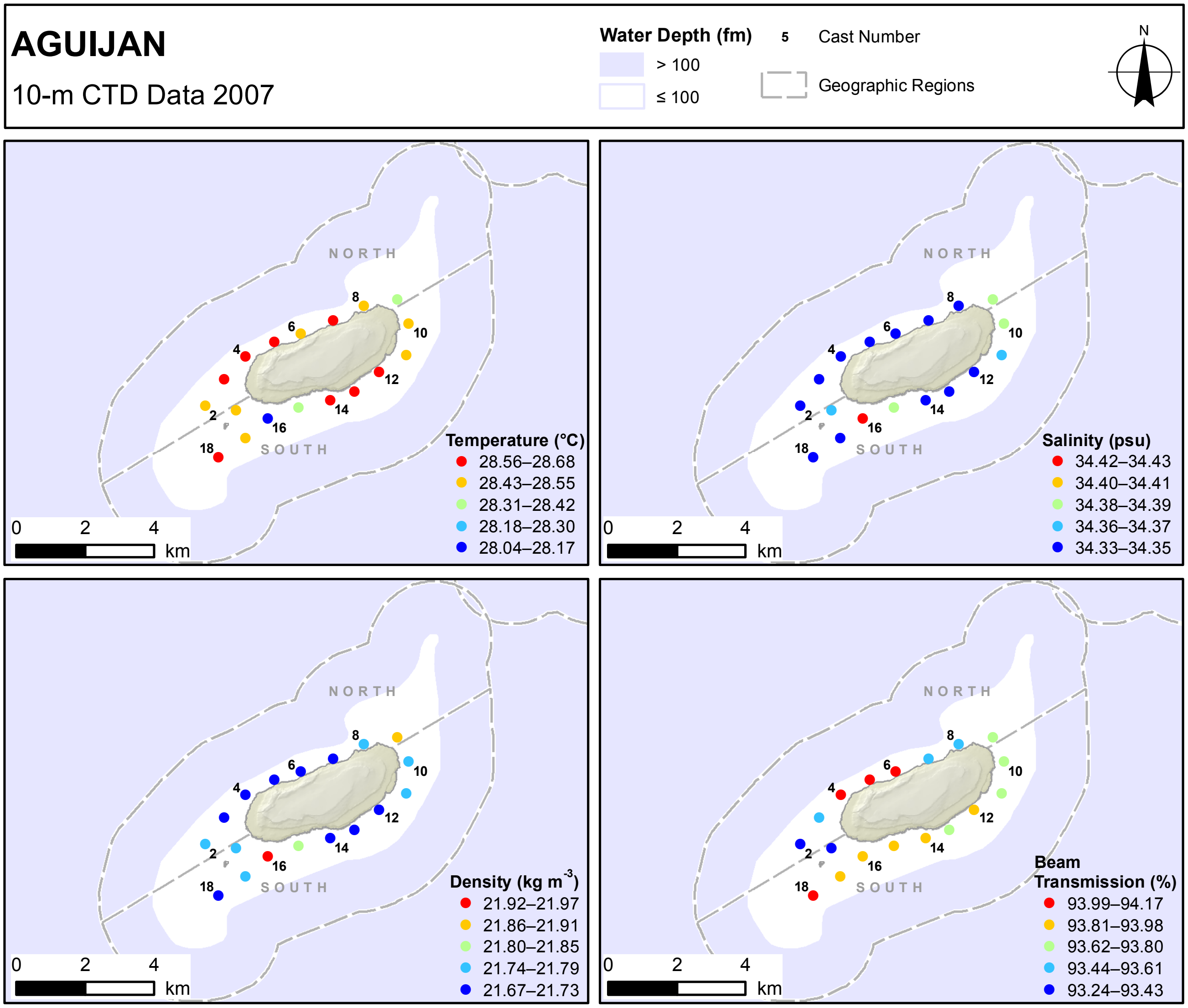


Figure 6.4.1f. Values of (*top left*) water temperature, (*top right*) salinity, (*bottom left*) density, (*bottom right*) and beam transmission at a 10-m depth from shallow-water CTD casts around Aguijan on May 18 during MARAMP 2007.

Water samples were collected in concert with shallow-water CTD casts at 3 select locations at Aguijan in 2007 to assess water-quality conditions. The following ranges of measured parameters were recorded: Chl-*a*, 0.03–0.05 µg L^{-1}; total nitrogen (TN), 0.01–0.03 µM; nitrate (NO_3^-), 0.01–0.02 µM; nitrite (NO_2^-), 0.001–0.005 µM; phosphate (PO_4^{3-}), 0.05–0.054 µM; and silicate [$Si(OH)_4$], 0.49–0.61 µM. Comparisons of all parameters measured around Aguijan suggest homogeneity among locations (Fig. 6.4.1h).

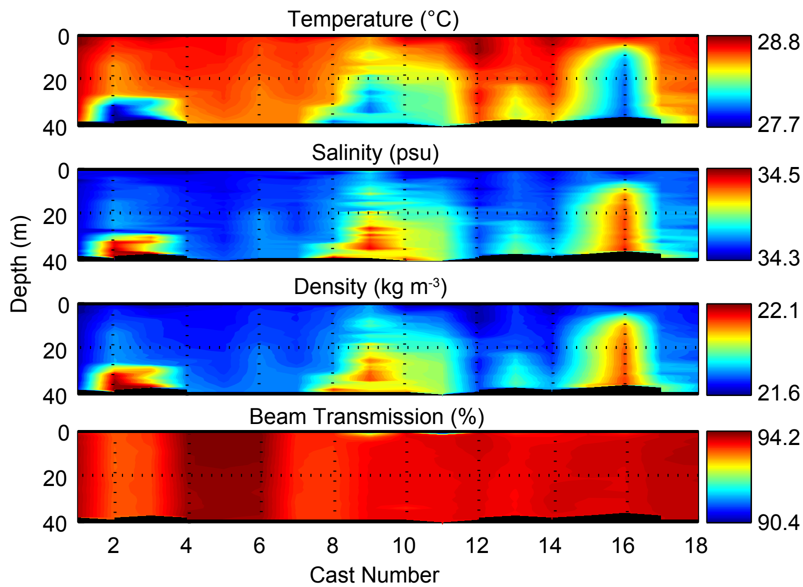


Figure 6.4.1g. Shallow-water CTD cast profiles to a 30-m depth around Aguijan on May 18 during MARAMP 2007, including temperature (°C), salinity (psu), density (kg m^{-3}), and beam transmission (%). Profiles, shown sequentially in a left-to-right direction in this graph, correspond to cast locations that are numbered sequentially 1–18 in a clockwise direction around Aguijan. For cast locations and numbers around this island in 2007, see Figure 6.4.1f.

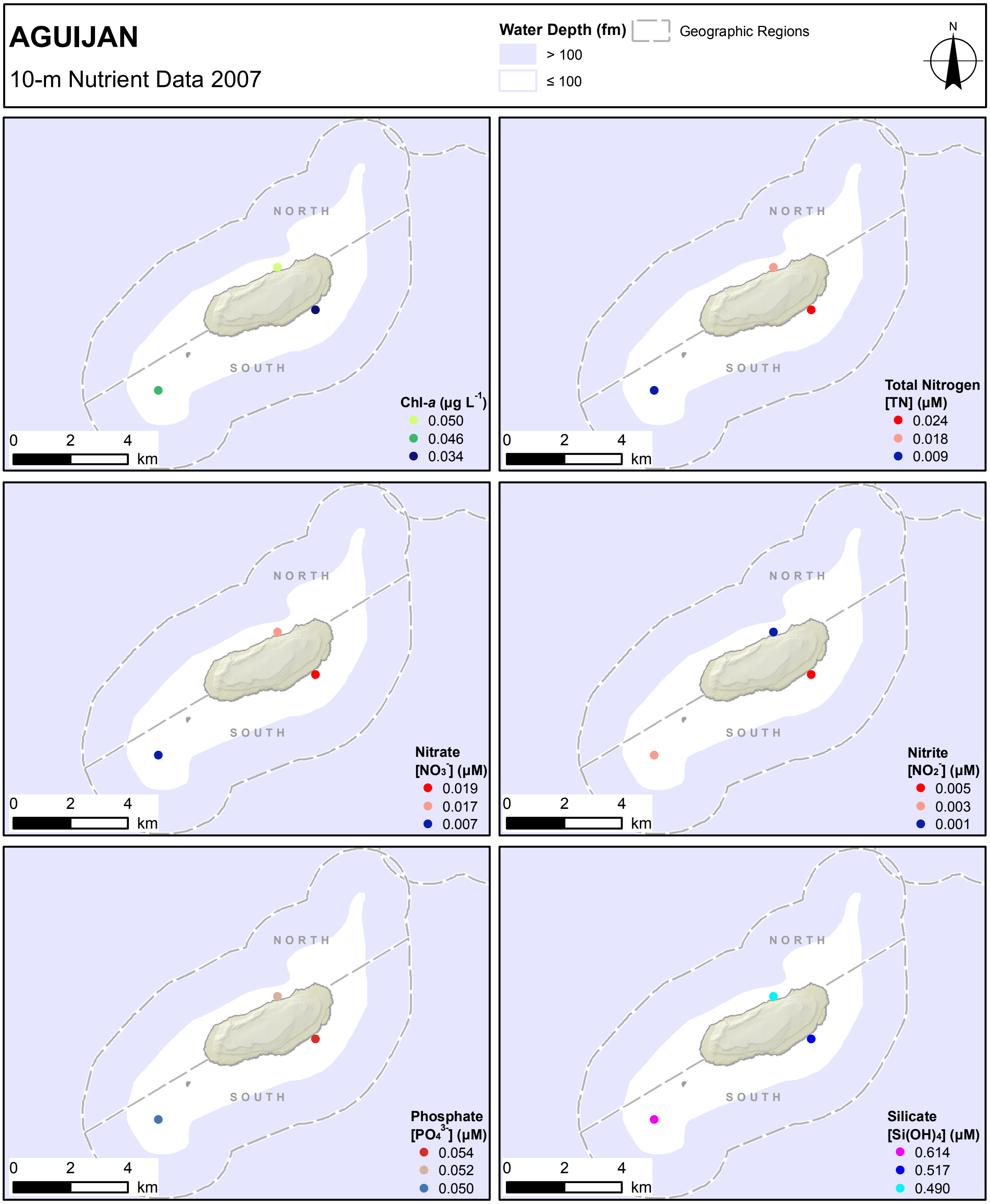


Figure 6.4.1h. Concentrations of (*top left*) Chl-*a*, (*top right*) total nitrogen, (*middle left*) nitrate, (*middle right*) nitrite, (*bottom left*) phosphate, and (*bottom right*) silicate at a 10-m depth, from water samples collected at Aguijan May 18 during MARAMP 2007.

Temporal Comparison

Data from shallow-water CTD casts performed around Aguijan during MARAMP 2003, 2005, and 2007 show temperature ranges > 1°C within these survey periods. Cold-water intrusions, with associated higher salinities and higher densities, were observed during each MARAMP survey year. The mechanism behind these intrusions is unknown, since there is no clear spatial pattern and they occurred at variable depths. Beam transmission was relatively high (93.36%–97.06%) in the 3 survey years, suggesting that terrestrial runoff was low in the vicinity of Aguijan during MARAMP surveys.

Water-quality data obtained during MARAMP 2005 and 2007 indicate that Chl-*a*, total nitrogen, nitrate, nitrite, and silicate concentrations were much lower in 2007 than in 2005, while phosphorus was slightly higher. Whether a reduction in the majority of nutrient levels was the result of a seasonal effect or some other process is unknown at this time. MARAMP 2005 occurred during a period of seasonally high precipitation, while MARAMP 2007 occurred during a period of seasonally low precipitation (see Chapter 3: "Archipelagic Comparisons," Section 3.3.1: "Seasonal Climatologies" for precipitation information).

6.4.2 Time-series Observations

Between 2003 and 2007, a subsurface temperature recorder (STR) was deployed at a single mooring site at Aguijan at a depth of 8 m to collect time-series observations of a key oceanographic parameter (Figs. 6.4.2a and b). The location, depth, time frame, and other details about deployments at this site are provided in Figures 6.4.2a and b.

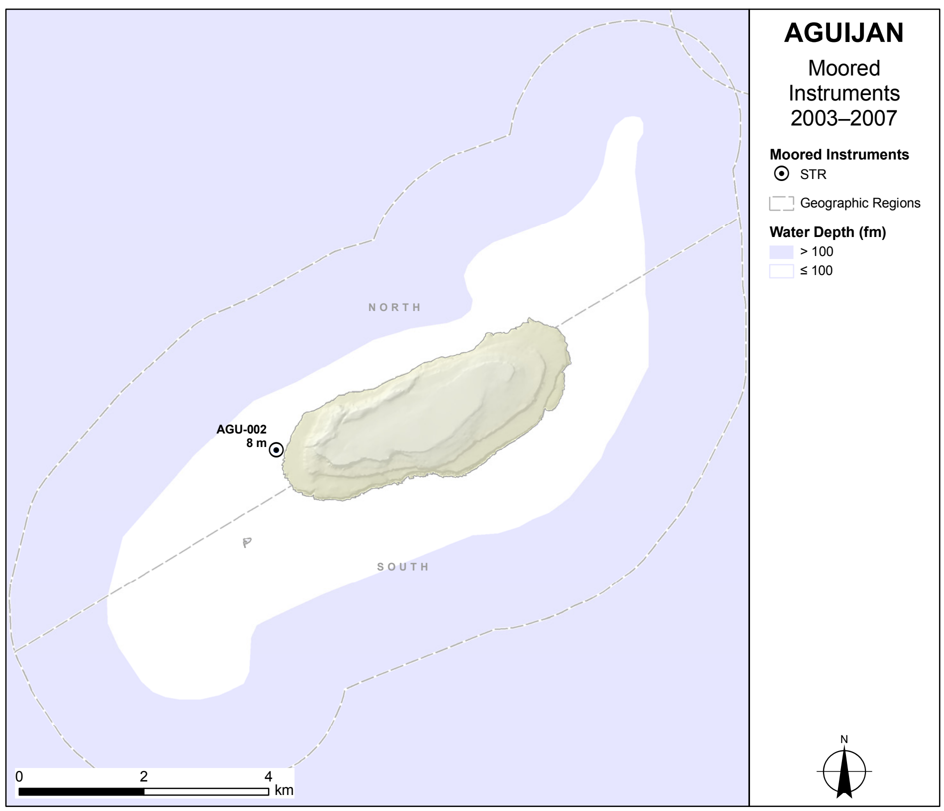


Figure 6.4.2a. Location and depth of the subsurface temperature recorder (STR) deployed at Aguijan during MARAMP 2003, 2005, and 2007.

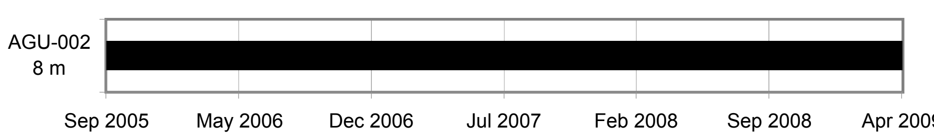


Figure 6.4.2b. Deployment timeline and depth of the STR moored at Aguijan during the period from September 2005 to April 2009. A solid bar indicates the period for which temperature data were collected by the STR deployed and retrieved at the mooring site.

Temperature data from the STR at this mooring site showed predominantly seasonal temperature variability of 3°C–3.5°C (Fig. 6.4.2c). Water temperatures reached ~ 31°C during the period of June–October and fell to a low of ~ 27°C during the period of January–May. Temperatures in September 2006 reached and surpassed the coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean. Diurnal temperature fluctuation was consistently ~ 0.3°C during this time series.

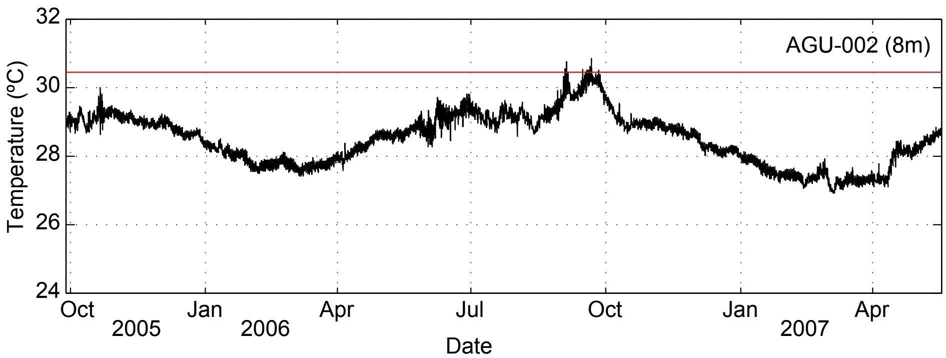


Figure 6.4.2c. Time-series observations of temperature over the period between October 2005 and June 2007 collected from 1 STR mooring site at Aguijan at a depth of 8 m (see Figure 6.4.2a for the mooring location). The red line indicates the satellite-derived coral bleaching threshold, which is defined as 1°C above the monthly maximum climatological mean.

6.5 Corals and Coral Disease

6.5.1 Coral Surveys

Coral Cover and Colony Density

From MARAMP 2003 towed-diver surveys, mean cover of live hard corals on forereef habitats at the island of Aguijan and the reef area at Naftan Rock was 18% (SE 1.9). Coral cover was lowest in the south region of Aguijan and at Naftan Rock with a mean of 12% for 30 survey segments; only 1 segment there had an estimate of coral cover > 20% (Fig. 6.5.1a, top panel). Coral cover was highest along the northwestern coast of Aguijan with a mean of 34% for 10 segments.

From MARAMP 2005 towed-diver surveys, mean cover of live hard corals on forereef habitats around Aguijan was 17% (SE 1.8). Coral cover was highest along the west coast of Aguijan with a mean of 35% for 11 segments (Fig. 6.5.1a, middle panel). High levels of coral cover, relative to other areas surveyed at Aguijan, also were noted in the north region with a mean of 42% for 3 segments. Coral cover was lowest along the southeastern coast of Aguijan with a mean of 7% for 20 segments. Towed divers recorded estimates of stressed-coral cover, including corals that were fully bleached (white), pale or discolored, malformed, or stricken with tumors (see Chapter 2: "Methods and Operational Background," Section 2.4.5, "Corals and Coral Disease"). Overall, 0.6% (SE 0.1) of coral cover observed on forereef habitats around Aguijan appeared stressed. Stressed-coral cover recorded at Aguijan never exceeded 5%.

From MARAMP 2007 towed-diver surveys, mean cover of live hard corals on forereef habitats at Aguijan was 12% (SE 1.2). Only 3 surveys were conducted at Aguijan in 2007 with low coral cover observed in all survey areas except for a single area along the northeastern coast with a mean of 25% for 2 segments (Fig. 6.5.1a, bottom panel). Overall, 7.5% (SE 1.1) of coral cover observed on forereef habitats at Aguijan appeared stressed. Stressed-coral cover was highest for the 2 surveys conducted along the western and southern shores, each with a mean of 10.8% for 20 segments (Fig. 6.5.1a, bottom panel). Stressed-coral cover was considerably higher in these areas in 2007 than in 2005; however, no additional observations were collected by towed divers that would explain the higher level in 2007. Values were lowest around the east coast, where no segment had stressed-coral cover exceeding 5%.

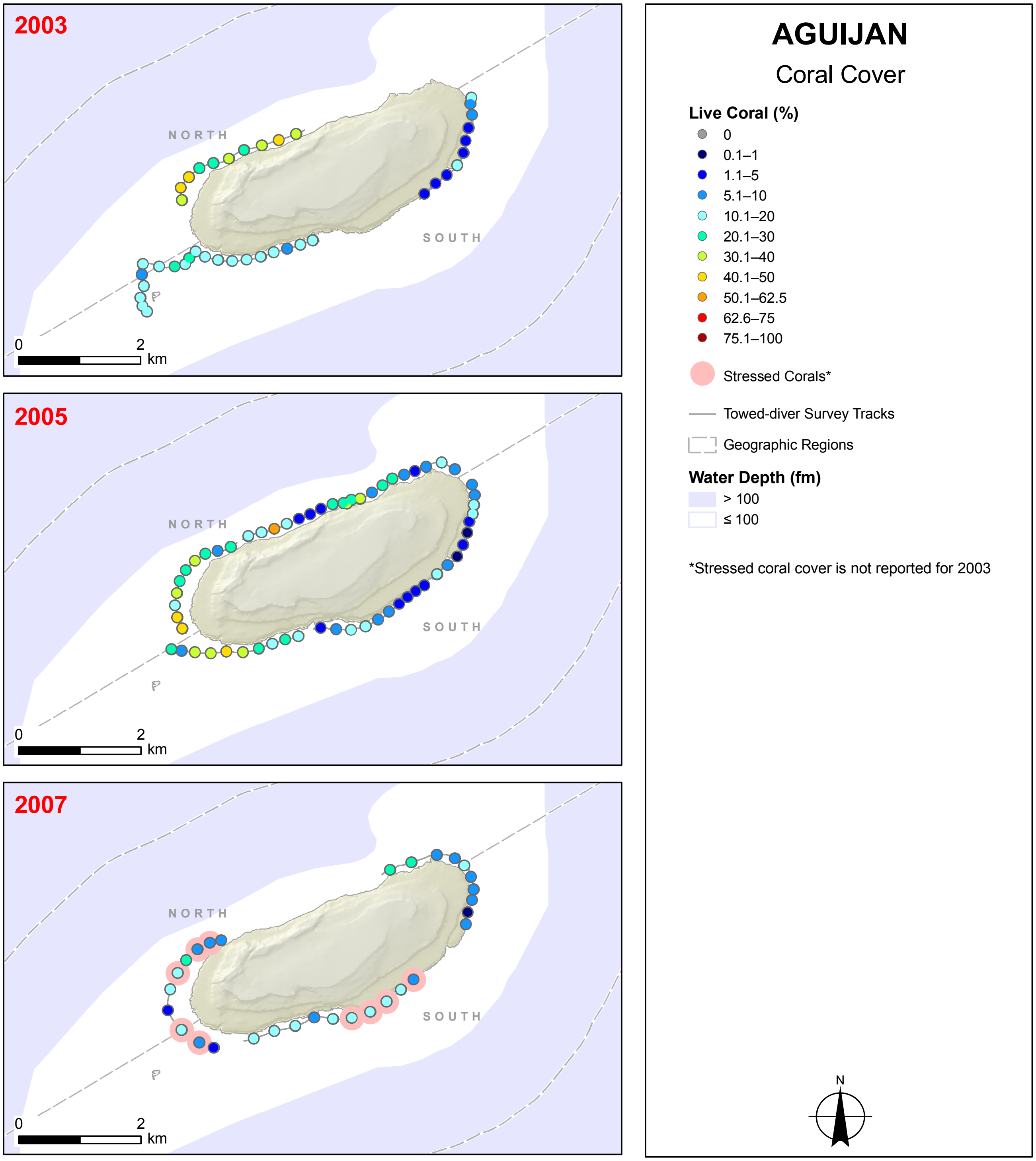


Figure 6.5.1a. Cover (%) observations of live and stressed hard corals from towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007. Each colored point represents an estimate of live coral cover over a 5-min observation segment with a survey swath of ~ 200 x 10 m (~ 2000 m^2). Pink symbols represent segments where estimates of stressed-coral cover were > 10%. Stressed-coral cover was measured as a percentage of overall coral cover in 2005 and 2007.

During MARAMP 2003, 2 REA benthic surveys using the quadrat method on forereef habitats at Aguijan documented 204 coral colonies within a total survey area of 7.5 m^2. Site-specific colony density ranged from 21.9 to 32.5 colonies m^{-2} with an overall sample mean of 27.2 colonies m^{-2} (SE 5.3). The highest colony density was recorded at AGU-02 on the northwestern coast, and the lowest colony density was observed at AGU-01 on the southeastern coast (Fig. 6.5.1b, top panel).

During MARAMP 2005, 3 REA benthic surveys using the quadrat method on forereef habitats at Aguijan documented 470 coral colonies within a total survey area of 12 m^2. Site-specific colony density ranged from 27.5 to 47.8 colonies m^{-2} with an overall sample mean of 39.2 colonies m^{-2} (SE 6.1). The highest colony density was recorded at AGU-03 in the north region. Similar to estimates from MARAMP 2003 surveys, the lowest colony density was observed at AGU-01 in the south region (Fig. 6.5.1b, middle panel).

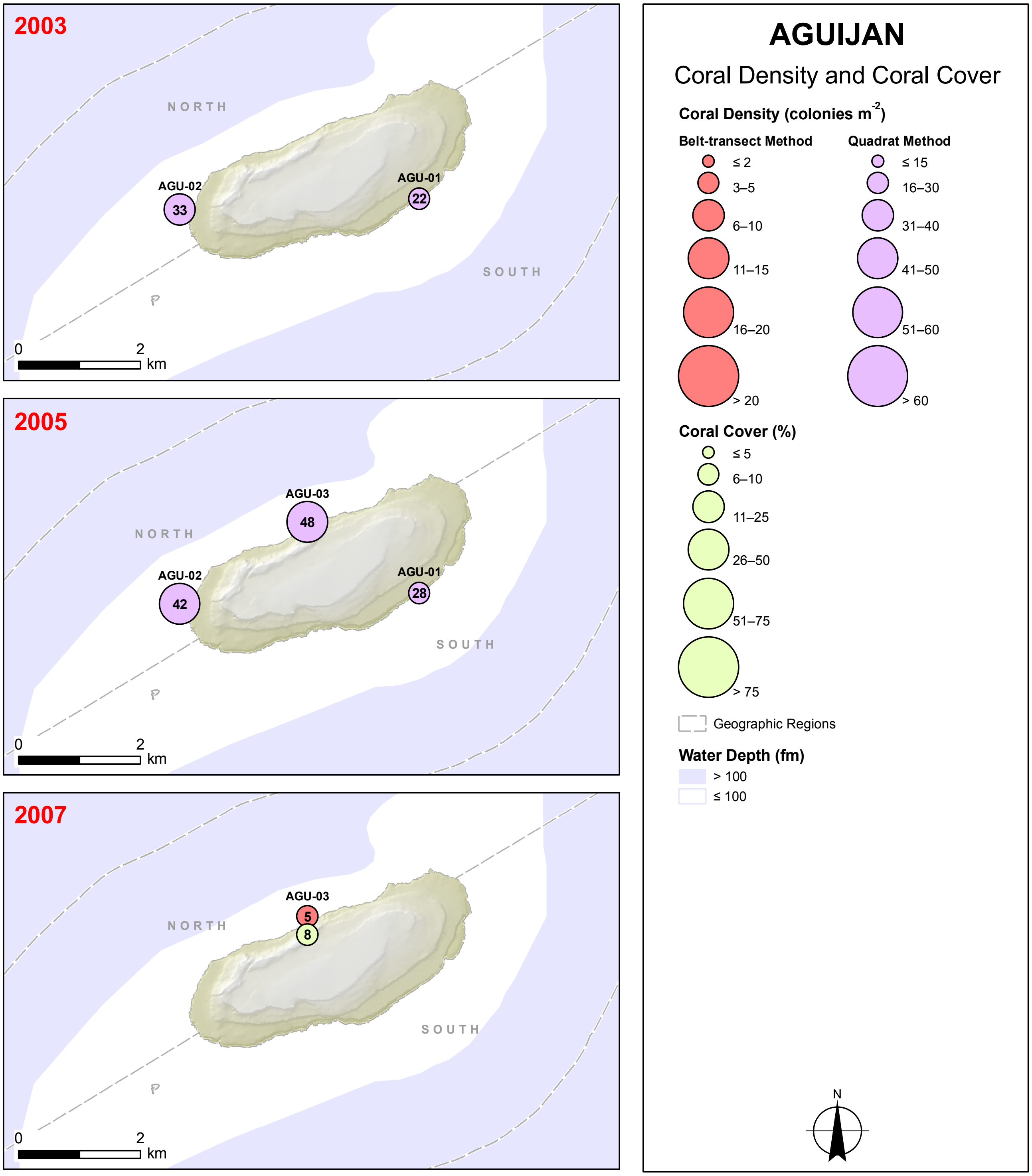


Figure 6.5.1b. Colony-density (colonies m^{-2}) observations of live hard corals from REA benthic surveys of forereef habitats conducted at Aguijan during MARAMP 2003, 2005, and 2007, and cover (%) observations of live corals from REA benthic surveys during MARAMP 2007. Values are provided within each symbol. The quadrat method was used in 2003 and 2005 to assess coral-colony density, but the belt-transect method was used in 2007.

During MARAMP 2007, 1 REA benthic survey using the line-point-intercept method was conducted on a forereef habitat at Aguijan. The estimate of live-hard-coral cover at AGU-03 in the north region was low at 7.8% (Fig. 6.5.1b, bottom panel).

During MARAMP 2007, 1 REA benthic survey using the belt-transect method on a forereef habitat at Aguijan documented 226 coral colonies within a total survey area of 50 m^2. Colony density was 4.5 colonies m^{-2} at AGU-03 (Fig. 6.5.1b, bottom panel).

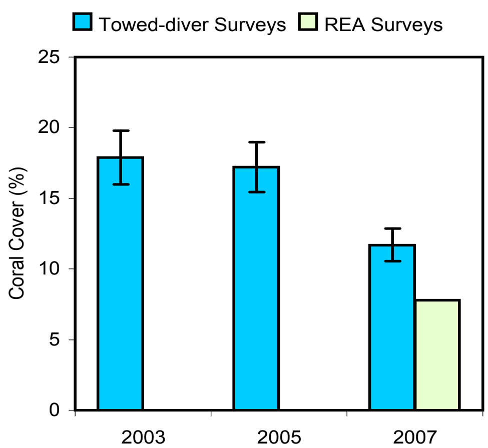


Figure 6.5.1c. Temporal comparison of mean live coral cover (%) from REA and towed-diver benthic surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. No REA surveys using the line-point-intercept method were conducted around Aguijan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

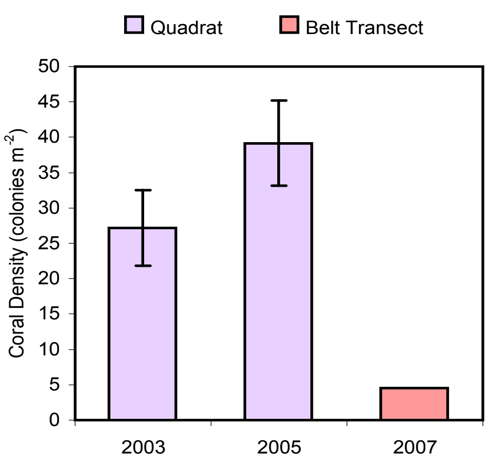


Figure 6.5.1d. Temporal comparison of mean coral-colony densities (colonies m^{-2}) from REA benthic surveys conducted on forereef habitats at Aguijan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to measure coral-colony density, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.

Islandwide mean cover of live corals, estimated from towed-diver surveys of forereef habitats, was nearly the same in 2003 and 2005 at 18% (SE 1.9) and 17% (SE 1.8) but lower in 2007 at 12% (SE 1.2) in 2007 (Fig. 6.5.1c). This relatively small variation in overall mean values of live coral cover between MARAMP survey years does not necessarily reflect actual changes in overall coral cover (For information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Coral cover was 7.8% at the 1 REA site surveyed in 2007, AGU-03, a value that is congruent with estimates from towed-diver surveys conducted in this area in 2005 (towed-diver surveys in 2007 were not conducted along the north central coast, where AGU-03 was located. Aguijan was not surveyed for coral cover using the line-point-intercept method in 2003 or 2005).

During MARAMP 2003 and 2005, REA benthic surveys of forereef habitats were conducted using the quadrat method at Aguijan. Overall mean coral-colony density from REA benthic surveys of forereef habitats at Aguijan varied from 27.2 (SE 5.3) colonies m^{-2} in 2003 to 39.2 (SE 6.1) colonies m^{-2} in 2005 (Fig. 6.5.1d). The higher mean value in 2005 primarily results from a high colony density of 47.8 colonies m^{-2} at AGU-03, which was surveyed in 2005 but not in 2003. At AGU-03, the only site surveyed during MARAMP 2007, coral-colony density appeared substantially lower, with 4.5 colonies m^{-2}, than the overall density observed in 2005. This difference, however, is likely a result of the use of different methods to assess colony density. The method of placing quadrats used in 2003 and 2005 was highly biased towards surveying hard-bottom substrate where coral was present, whereas the belt-transect method used in 2007 assessed benthos that fell within the transect belt regardless of the nature of the substrate.

Coral Generic Richness and Relative Abundance

Two REA benthic surveys of forereef habitats were conducted using the quadrat method at Aguijan during MARAMP 2003. At least 30 coral genera were observed at Aguijan. Generic richness was 15 at AGU-01 in the south region and 17 at AGU-02 on the west coast in the north region with a mean of 16 (SE 1) coral genera per site (Fig. 6.5.1e, top panel). *Leptastrea*, *Favia*, and *Pocillopora* were the most numerically abundant genera, contributing 25.1%, 14.5%, and 13.3% of the total number of colonies enumerated at Aguijan. All other genera individually contributed < 10% of the total number of colonies. *Leptastrea* dominated the coral fauna at both sites, contributing 32.9% of the total number of colonies at AGU-01 and 17.2% of the colonies at AGU-02. *Porites* and *Astreopora,* in addition to *Favia* and *Pocillopora,* contributed > 10% to the total number of colonies at AGU-02.

Three REA benthic surveys of forereef habitats were conducted using the quadrat method at Aguijan during MARAMP 2005. At least 24 coral genera were observed at Aguijan. Generic richness ranged from 13 to 19 with a mean of 16 (SE 1.7) coral genera per site (Fig. 6.5.1e, middle panel). The highest generic diversity was seen at AGU-02 in the north region, and the lowest diversity was recorded at AGU-01 on the southeastern coast. *Leptastrea, Favia*, and *Pavona* were the most numerically abundant genera, contributing 18.5%, 14.0%, and 14.1% of the total number of colonies enumerated at Aguijan. All other genera individually contributed < 10% to the total number of colonies. Site-specific dominance patterns,

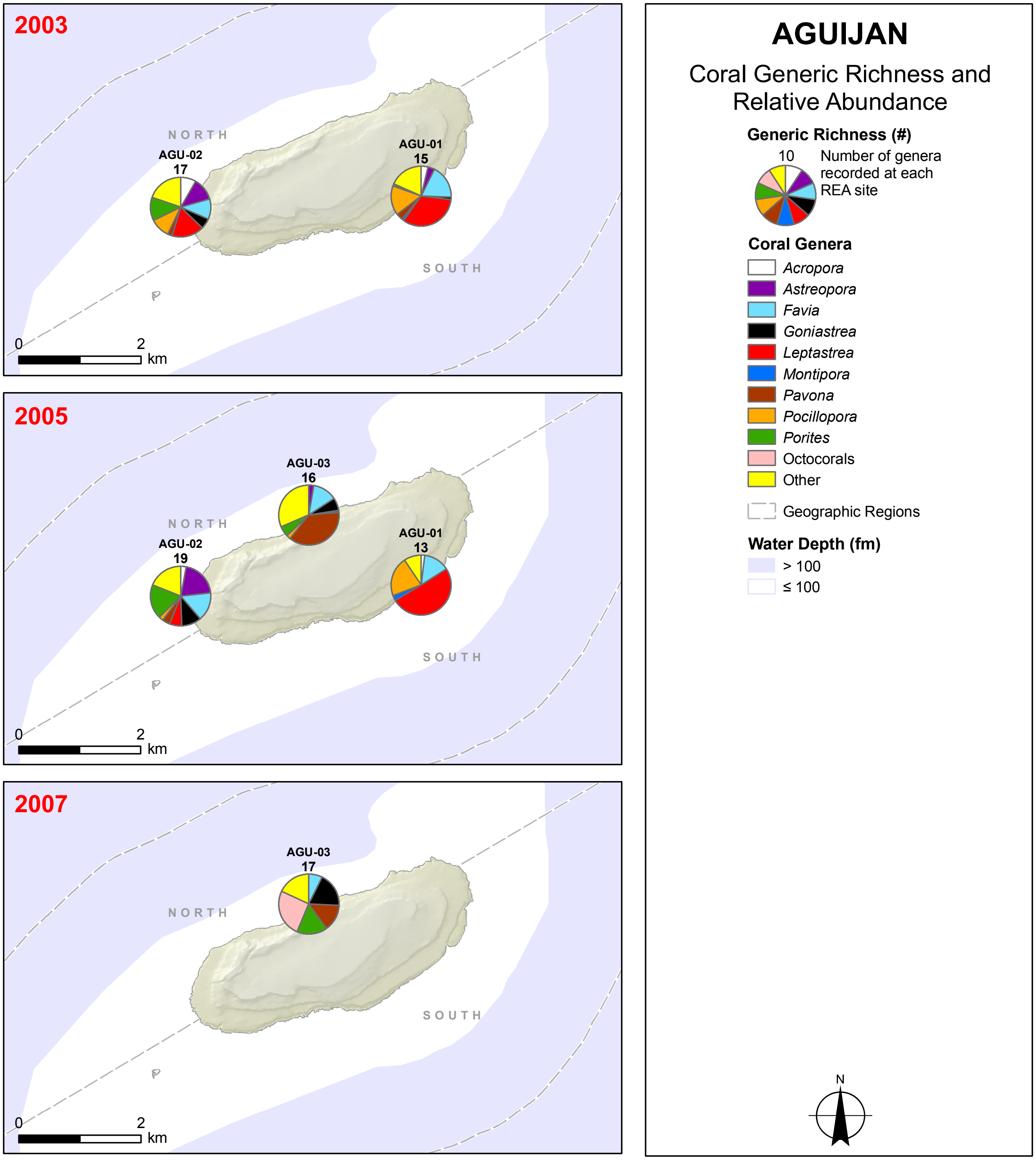


Figure 6.5.1e. Observations of coral generic richness and relative abundance of coral genera from REA benthic surveys of forereef habitats conducted at Aguijan during MARAMP 2003, 2005, and 2007. The pie charts indicate percentages of relative abundance of key coral genera. The quadrat method was used in 2003 and 2005 to survey coral genera, but the belt-transect method was used in 2007.

however, varied somewhat from the overall average. *Leptastrea* dominated the coral fauna at AGU-01, contributing 49.1% of the total number of colonies recorded. *Astreopora* and *Porites* dominated at AGU-02, contributing 20.1% and 18.3% of the total number of colonies. *Pavona* dominated at AGU-03 in the north region, contributing 37.2% of the total number of colonies, while *Leptastrea* was not recorded at AGU-03.

One REA benthic survey of a forereef habitat was conducted using the belt-transect method at Aguijan during MARAMP 2007. At least 17 coral genera were observed at AGU-03 on the north central shore (Fig. 6.5.1e, bottom panel), including 3 genera that had not been recorded at Aguijan in 2003 or 2005: *Coscinaraea*, *Lobophytum*, and *Sinularia*. Octocorals (*Lobophytum* and *Sinularia*), *Goniastrea*, *Porites*, and *Pavona* were the most numerically abundant taxa, contributing 25.2% (octocorals combined), 18.1%, 15.9%, and 14.2% of the total number of colonies enumerated. All other genera individually contributed < 10% to the total number of colonies.

Site-specific estimates of generic richness across the 3 MARAMP survey years ranged from 13 to 19 on forereef habitats at Aguijan (Fig. 6.5.1f). All 3 REA sites were surveyed twice, at a biennial interval, and at each site the number of genera did not vary substantially between survey years. Overall mean generic richness values were quite consistent between survey years with 16–17 genera per site. The number of genera recorded in the north region at AGU-03 was similar in both 2005 and 2007 (16 and 17 genera). This consistency in generic diversity was observed despite differences in the survey methods used. The only octocoral genus assessed in 2003 and 2005 was *Heliopora*, whereas all octocoral genera were assessed in 2007. The size of the areas in which corals were censused were different between methods: the survey area in 2007 was 50 m^2 per site, much larger than the 3.75–4 m^2 per site surveyed in 2003 and 2005 (see Chapter 2: "Methods," Section 2.4.5: "Corals and Coral Disease").

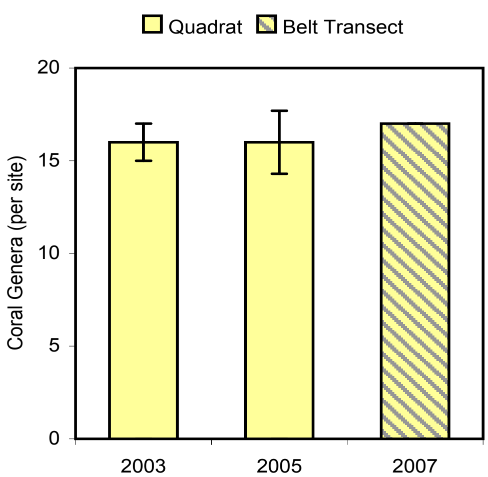


Figure 6.5.1f. Temporal comparison of overall mean numbers of coral genera per site from REA benthic surveys conducted on forereef habitats at Aguijan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to survey coral genera, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.

During the 3 survey years, 32 coral genera were observed on forereef habitats at Aguijan. *Leptastrea*, *Favia*, *Pavona*, *Pocillopora*, *Astreopora*, and *Porites* were important components of the coral fauna. As determined from the 3 sites surveyed in 2005, *Leptastrea*, *Favia*, and *Pavona* dominated the coral fauna, accounting for 18.5%, 14.2%, and 14.1% of the total number of colonies enumerated at Aguijan. However, considerable variability between sites was observed. For example, *Leptastrea* was particularly abundant at AGU-01 in the south region, accounting for 49.1% of the number of colonies, but was absent from AGU-03 in the north region, where *Pavona* dominated the coral fauna. At AGU-01, surveyed in 2003 and 2005, *Leptastrea*, *Pocillopora*, and *Favia* were the 3 most numerically abundant taxa. On the northwestern coast at AGU-02, also surveyed in 2003 and 2005, *Leptastrea*, A*strepora*, and *Porites* were the 3 most numerically abundant taxa in 2003, but *Favia* replaced *Leptastrea* as 1 of the 3 most abundant taxa in 2005. At AGU-03, surveyed in 2005 and 2007, *Pavona*, *Favia*, and *Goniastrea* were the most numerically abundant taxa in 2005, but octocorals replaced *Favia* as 1 of the 3 most abundant taxa in 2007.

Coral Size-class Distribution

During MARAMP 2003, 2 REA benthic surveys of forereef habitats were conducted at Aguijan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (56.3%) of corals had maximum diameters ≤ 5 cm (Fig. 6.5.1g, top panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 25.5%, 6.9%, and 11.2% of colonies recorded at Aguijan. No colonies measuring > 40 cm in maximum diameter were recorded. At both AGU-01, in the south region, and AGU-02, in the north region, high proportions (89% and 74.6%) of colonies enumerated were small (≤ 10 cm) and correspondingly low proportions (11% and 25.4%) of observed colonies were midsize (11–40 cm).

During MARAMP 2005, 3 REA benthic surveys of forereef habitats were conducted at Aguijan using the quadrat method. The coral size-class distribution from these surveys shows that the majority (73.6%) of corals had maximum diameters ≤ 5 cm (Fig. 6.5.1g, middle panel). The next 3 size classes (6–10, 11–20, and 21–40 cm) accounted for 18.8%, 5.7%, and 1.8% of colonies recorded at Aguijan, and size classes > 40 cm accounted for 0.2% of colonies recorded. High proportions of colonies found at all 3 REA sites fell into the 2 smallest size classes (≤ 10 cm): 95.5% for AGU-01, in the south region, as well as 85.8% and 95.8% for AGU-02 and AGU-03 in the north region. Correspondingly low proportions (4.5%, 13.6%, and 4.2%) of observed colonies were midsize (11–40 cm) at these 3 sites.

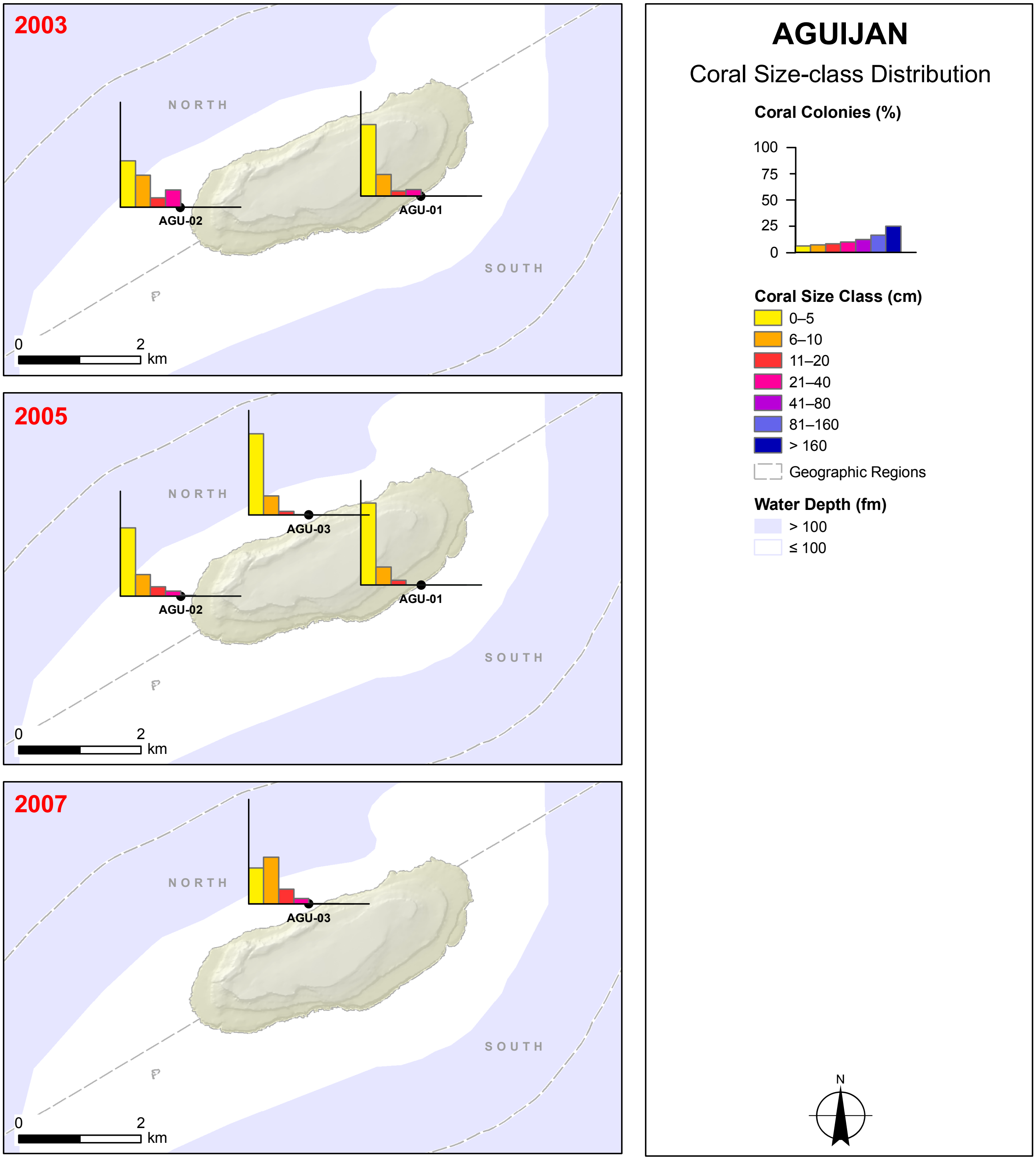


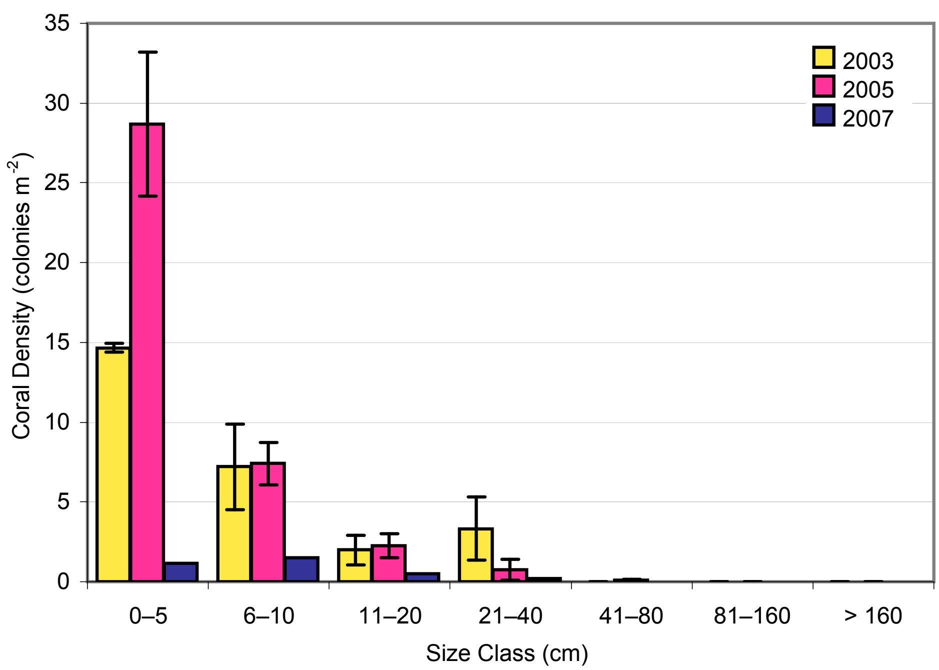
Figure 6.5.1g. Size-class distributions of hard corals from REA benthic surveys of forereef habitats conducted at Aguijan during MARAMP 2003, 2005, and 2007. The observed size classes are color coded in a size-frequency chart at each REA site. The quadrat method was used in 2003 and 2005 to size corals, but the belt-transect method was used in 2007.

During MARAMP 2007, 1 REA benthic survey of a forereef habitat was conducted at Aguijan using the belt-transect method. The coral size-class distribution from this survey shows that the majority (79.2%) of corals had maximum diameters ≤ 10 cm (Fig. 6.5.1g, bottom panel). The next 4 size classes (0–5, 6–10, 11–20, and 21–40 cm) accounted for 34.5%, 44.6%, 14.3%, and 5.4% of colonies recorded, and size classes > 40 cm accounted for 1.2% of colonies recorded.

Site-specific and overall distributions of estimated coral size classes on forereef habitats at Aguijan are affected by inherent biases in the methods used to census and size corals. During MARAMP 2003 and 2005, corals whose center fell within the borders of a quadrat (50 × 50 cm) were tallied and measured in 2 planar dimensions to the nearest centimeter. Fewer large colonies than small colonies can fall within a quadrat. This bias can contribute to higher counts of colonies in the smallest size classes and lower counts of colonies in the largest size classes compared to the actual relative colony densities. At each site, 15 or 16 such quadrats were examined (total survey area = 3.75 or 4 m^2), enabling the observer to closely inspect and record each coral colony within the quadrat. During MARAMP 2007, corals whose center fell within a belt transect (1 × 25 m) were tallied and binned into 1 of 7 size classes based on visual estimates of maximum colony diameter. This method is better suited to capturing large colonies, but the larger census area likely reduces the number of very small colonies (≤ 5 cm) that are observed and recorded. For more on these survey methods, see Chapter 2: “Methods and Operational Background,” Section 2.4.5, “Corals and Coral Disease.”

These methodological biases are reflected in the size-class data by survey year. Estimates of coral densities on forereef habitats were much higher in the first 2 MARAMP survey years compared to 2007 (Fig. 6.5.1h). In 2003 and 2005, more than half (56.3% and 73.6%) of all colonies censused at Aguijan had a maximum diameter ≤ 5 cm, but in 2007 only 34.5% of the observed colonies were in this smallest size class. Comparing size-class data between survey years when different methods were used is, therefore, inappropriate. Only REA sites AGU-01 in the south region and AGU-02 in the north region were surveyed with the same quadrat method in 2 different survey years (2003 and 2005). At these sites, the changes in size-class distributions between survey years likely results from chance variation in the placement of individual quadrats.

Figure 6.5.1h. Mean coral-colony densities (colonies m^{-2}) by size class from REA benthic surveys of forereef habitats conducted at Aguijan during MARAMP 2003, 2005, and 2007. The quadrat method was used in 2003 and 2005 to size corals, but the belt-transect method was used in 2007. Error bars indicate standard error (± 1 SE) of the mean.



6.5.2 Surveys for Coral Disease and Predation

During MARAMP 2007, a REA benthic survey for coral disease and predation was conducted using the belt-transect method at 1 site on a forereef habitat at Aguijan, covering a total area of 200 m^2. Overall prevalence of disease at AGU-03 was 0.5%. This site contained 2 cases of white syndrome on *Gardineroseris planulata*, amounting to a site-specific prevalence value of 0.3% (Fig. 6.5.2a). Additionally, one case of cyanophyte infection was detected at AGU-03 with a prevalence of 0.2%. No cases of coral predation were observed.

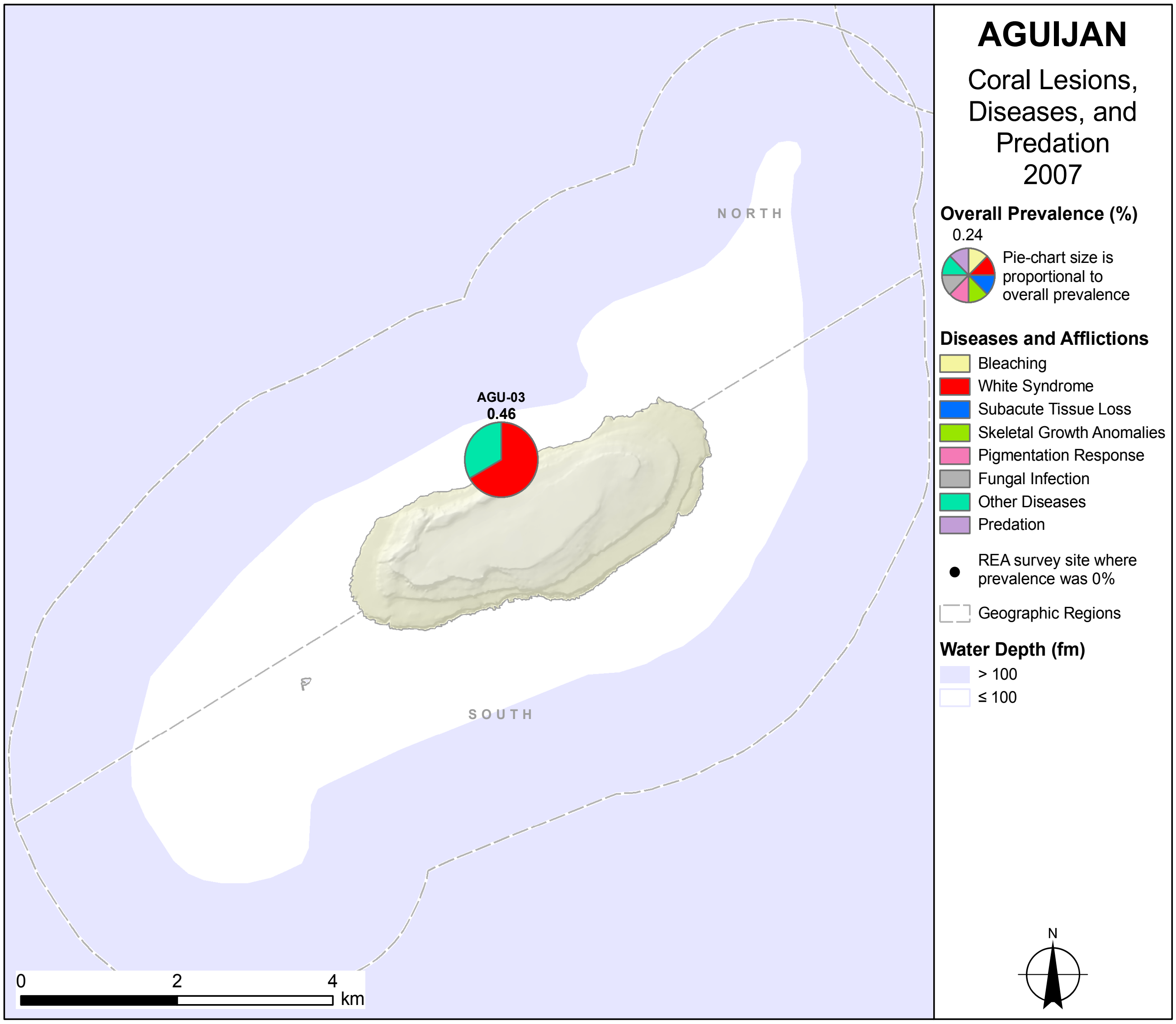


Figure 6.5.2a. Overall prevalence (%) observations of coral diseases and predation from a REA benthic survey of a forereef habitat conducted at Aguijan during MARAMP 2007. Prevalence was computed based on the estimated total number of coral colonies within the area surveyed for disease at the REA site. The color-coded portions of the pie chart indicate disease-specific prevalence.

6.6 Algae and Algal Disease

6.6.1 Algal Surveys

Algal Cover: Macroalgae and Turf Algae

From MARAMP 2003 towed-diver surveys, mean macroalgal cover on forereef habitats at the island of Aguijan was 45% (SE 3). Observations of macroalgal cover in 2003 included both macroalgae and turf algae. The survey with the highest mean macroalgal cover of 66%, within a range of 30.1%–100%, occurred along the southeastern, where pavement and rock boulders of medium complexity were the predominant types of habitat (Fig. 6.6.1a, top left panel). Two surveys, primarily in the south region, between Aguijan and Naftan Rock recorded a mean macroalgal cover of 44%, within a range of 20.1%–75%, where the habitat consisted predominantly of medium-low to medium complexity pavement. The lowest macroalgal cover was observed during 1 survey conducted in the north region with a mean of 24%, within a range 10.1%–30%, where spur-and-groove habitat, with sections of continuous reef, had medium-high to high complexity.

TOAD surveys completed south of Aguijan during MARAMP 2003 were conducted at depths of 15–100 m. Analyses of TOAD video footage obtained from 3 surveys suggests that little or no macroalgae existed in these areas (Fig 6.6.1a, top left panel). In some small sections, these surveys recorded macroalgal cover up to 80%, but no macroalgae were observed in the majority of images.

From MARAMP 2005 towed-diver surveys, mean cover of macroalgae on forereef habitats around Aguijan was 39% (SE 2.3). The survey with the highest mean macroalgal cover of 64%, within a range of 40.1%–100%, occurred along the southeastern coast, in an area of pavement and rock boulder habitat of medium-low to medium complexity (Fig. 6.6.1a, middle left panel). Species of the calcified, green macroalga *Halimeda* dominated the benthos in this area. Similarly, an adjacent survey to the southwest reported relatively high values of macroalgal cover with a mean of 52%, within a range of 30.1%–75%, in comparison to other surveys at Aguijan. The remaining surveys reported little variation with one exception: mean macroalgal cover was 38%, 34%, and 30%, within a range of 10.1%–62.5%, for 3 surveys, but a survey along the north central coast recorded macroalgal cover of 11%, within a range of 1.1%–20. Habitat complexity from these remaining surveys ranged primarily from medium-high to high.

From MARAMP 2007 towed-diver surveys, mean cover of macroalgae on forereef habitats at Aguijan was 28% (SE 3.5). As in 2003 and 2005, the survey with the highest macroalgal cover occurred along the southeastern coast (Fig. 6.6.1a, bottom left panel), with a mean of 36% within a range of 5.1%–75%. This area was characterized by cliffs, coral pavement and continuous reef, wide spur-and-groove formations, and moderate or steep slopes. Increases in cover of the green macroalgae genera *Halimeda* and *Microdictyon* were recorded in areas of continuous-reef habitat.

During MARAMP 2007, 1 REA benthic survey of forereef habitats was conducted using the line-point-intercept method at Aguijan. Mean macroalgal cover was 5.9% and mean turf-algal cover was 50% from this survey at AGU-03, the REA site located on the north central coast (Fig. 6.6.1b).

Algal Cover: Crustose Coralline Red Algae

From MARAMP 2003 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Aguijan was 15% (SE 1.5). The survey with highest mean crustose-coralline-red-algal cover of 27%, within a range of 10.1%–40%, occurred along the continuous-reef and spur-and-groove habitat on the northwestern coast (Fig. 6.6.1a, top right panel). Habitat complexity ranged from medium-high to high, and hard corals dominated this area. The remaining 3 surveys recorded means of 8%, 10%, and 11% for cover of crustose coralline red algae. These surveys occurred in areas with less complex habitat, composed of pavement and rock boulders, which are less prone to development of crustose coralline red algae. No crustose coralline red algae were observed in the analyses of the video footage collected during TOAD surveys in 2003.

From MARAMP 2005 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats around Aguijan was 11% (SE 2.4). For most towed-diver surveys, mean cover was < 6%. The clear exception to this pattern, a survey with a mean cover of 43%, within a range of 10.1%–75%, occurred along the north central shore, where habitat complexity ranged from medium-high to high and several observations of orange band disease were noted on crustose coralline red algae (Figs. 6.6.1a, middle right panel, and 6.6.2a).

From MARAMP 2007 towed-diver surveys, mean cover of crustose coralline red algae on forereef habitats at Aguijan was 13% (SE 1.4). The survey with the highest mean cover of 15% occurred along the northwestern coast, in continuous-reef and spur-and-groove habitats of medium complexity (Fig. 6.6.1a, bottom right panel).

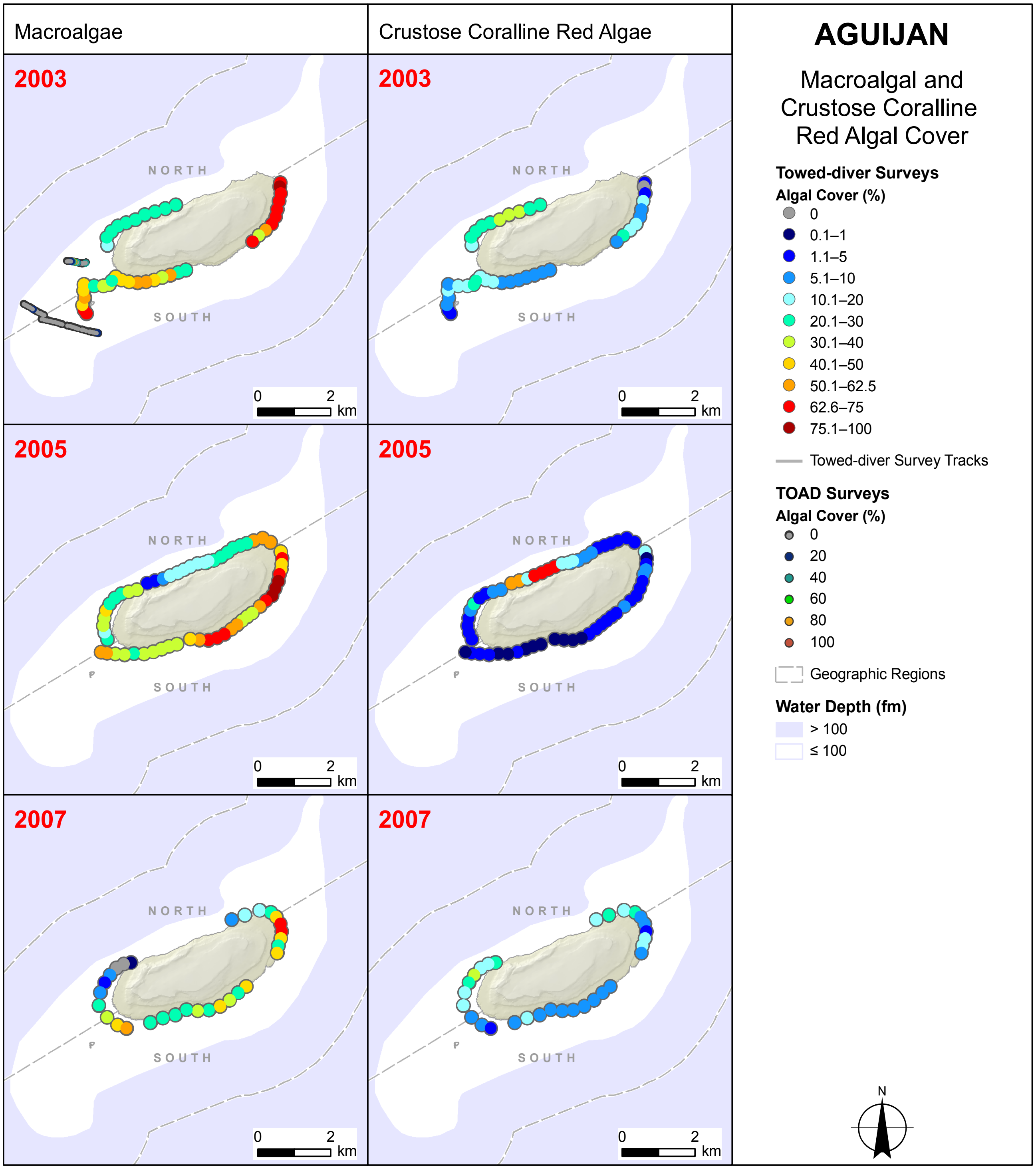
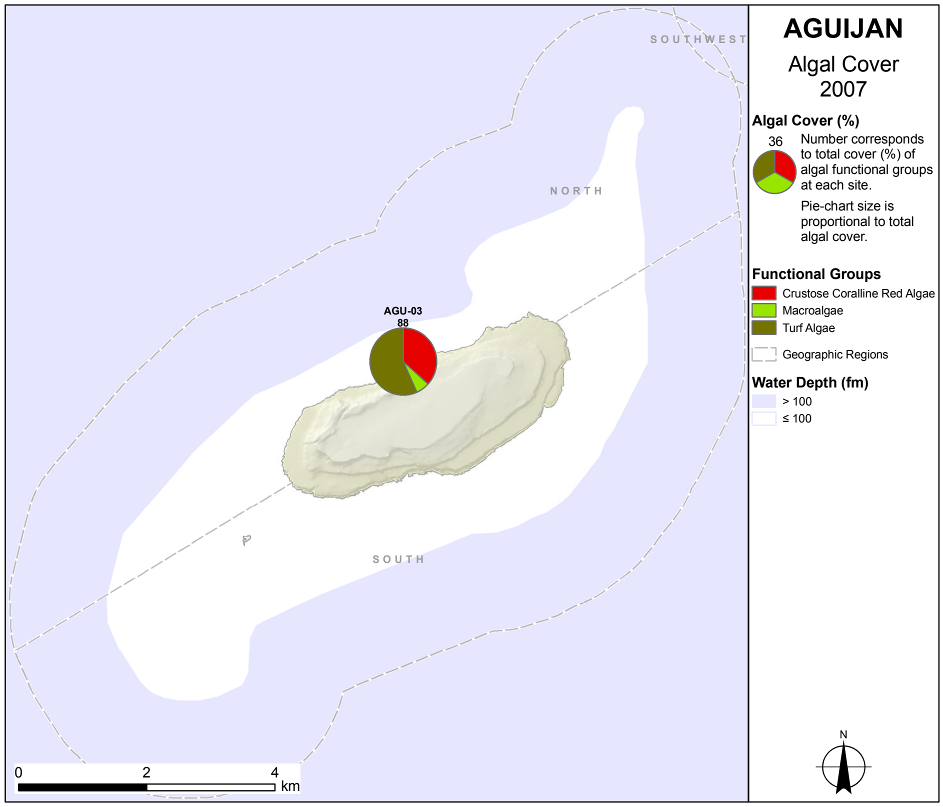


Figure 6.6.1a. Cover (%) observations of macroalgae and crustose coralline red algae from towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007. Each large, colored point represents an estimate over a 5-min observation segment with a survey swath of ~ 200 × 10 m (~ 2000 m²). The 2003 macroalgal panel shows observations of both macroalgae and turf algae (towed-diver surveys included turf algae only during MARAMP 2003). In this panel, each small, colored point represents an estimate of algal cover from TOAD surveys.

At the single REA site surveyed in 2007, AGU-03, mean crustose-coralline-red-algal cover was 32.4% (Fig. 6.6.1b).

Figure 6.6.1b. Observations of algal cover (%) from REA benthic survey of forereef habitats conducted using the line-point-intercept method at Aguijan during MARAMP 2007. The pie chart indicates algal cover by functional group, and the value of total algal cover is provided above the symbol.



Algal Cover: Temporal Comparison

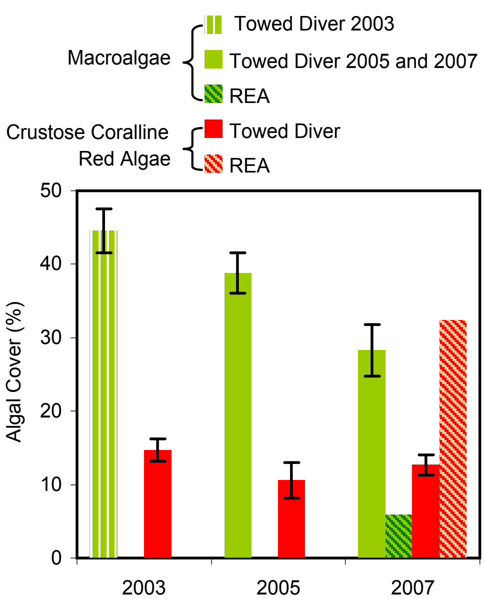


Figure 6.6.1c. Temporal comparison of algal-cover (%) values from surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Values of macroalgal cover from towed-diver surveys include turf algae only in 2003. No REA surveys using the line-point-intercept method were conducted at Aguijan in 2003 and 2005. Error bars indicate standard error (± 1 SE) of the mean.

Between MARAMP 2005 and 2007, islandwide mean cover of macroalgal populations around Aguijan, based on towed-diver surveys of forereef habitats, varied by 11% (Fig. 6.6.1c). In general, macroalgae most commonly inhabited pavement habitats, which had lower levels of complexity relative to other areas surveyed at Aguijan. The green algae *Halimeda* and *Microdictyon* were the most frequently observed genera. When considering survey results, keep in mind that turf algae were included, along with macroalgae, in towed-diver surveys of macroalgal cover only in 2003. Other factors, such as a change in season between survey periods, could have contributed to differences in macroalgal cover (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

Macroalgal cover from towed-diver surveys was lower in 2005 than in 2003 in nearly all areas surveyed at Aguijan, likely a result of including turf algae in the macroalgae category in 2003, although a small number of localized areas where macroalgal cover was higher were noted. During MARAMP 2005, 2 additional surveys were added to compliment the data set from MARAMP 2003, and this greater area of survey coverage reconfirmed that macroalgal cover was highest along reefs on the southeastern coast. For all survey areas, observed macroalgal cover appeared lower in 2007 than in 2005, but this result is uncertain because fewer surveys were conducted in 2007. The most noticeable decrease in macroalgal cover between these survey periods occurred along the northwestern coast.

Populations of crustose coralline red algae on forereef habitats around Aguijan, based on towed-diver surveys, essentially remained the same in islandwide mean cover of the benthos between MARAMP survey years. Crustose-coralline-red-algal cover was higher in continuous reef and spur-and-groove habitats of medium to medium-high complexity than in other types of habitats, while macroalgal cover appeared more prevalent in pavement and rock boulder habitats of medium-low to medium complexity.

Macroalgal Genera and Functional Groups

In the field, because of their small size or similarity in appearance, turf algae, crustose coralline red algae, cyanophytes (blue-green algae), and branched, nongeniculate coralline red algae were lumped into functional group categories. The generic names of macroalgae from field observations are tentative, since microscopic analysis is necessary for proper taxonomic identification. The lengthy process of laboratory-based taxonomic identification of all algal species collected at REA sites has not been undertaken yet for the southern islands of the Mariana Archipelago. Ultimately, based on microscopic analysis that may be done in the future, the generic names of macroalgae reported in this section may change and algal diversity reported for each REA site likely will increase.

During MARAMP 2003, REA benthic surveys were conducted at 2 sites on forereef habitats at Aguijan. In the field, 10 macroalgal genera (3 red and 7 green), containing at least 12 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. AGU-01 on the southeastern coast had the greater macroalgal generic diversity with 8 genera, containing 11 species, documented in the field. At AGU-02 on the northwestern coast, 2 species representing 2 genera were recorded (Fig. 6.6.1d, top panel).

The green macroalga *Halimeda* was the most common genus at both sites surveyed at Aguijan in 2003, occurring in 42% and 25% of sampled photoquadrats. The majority of the 12 algal species tentatively identified occurred only at AGU-01. The green algae *Dictyosphaeria* and *Caulerpa*, found in 25% and 33% of sampled photoquadrats, were the second- and third-most common genera at AGU-01. The remaining 5 genera observed at AGU-01 were equally abundant, all occurring in 8.33% of sampled photoquadrats. The only genus to occur at AGU-02 but not at AGU-01 was the green alga *Ventricaria*.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2003, occurring in 96%, 75%, and 37.5% of photoquadrats sampled at Aguijan. Turf algae were abundant at both sites, where they were found in > 92% of sampled photoquadrats. Crustose coralline red algae were observed in 66%–83% of sampled photoquadrats. Cyanobacteria were less common at both sites with individuals found in 25% of sampled photoquadrats at AGU-01 and in 50% at AGU-02.

During MARAMP 2005, REA benthic surveys were conducted at 3 sites on forereef habitats at Aguijan. In the field, 12 macroalgal genera (3 red, 6 green, and 3 brown), containing at least 12 species, as well as 4 additional algal functional groups—turf algae, crustose coralline red algae, branched nongeniculate coralline red algae, and cyanophytes—were observed. AGU-03 on the north central coast had the highest macroalgal generic diversity with 11 genera, containing 11 species, documented in the field. The lowest macroalgal generic diversity was found at AGU-02 on the northwestern coast with 5 species representing 5 genera recorded.

At all 3 REA sites surveyed at Aguijan in 2005, 5 algal genera were observeved (Fig. 6.6.1d, middle panel). Species of the genera *Halimeda* and *Dictyosphaeria* occurred in 42% and 25% of sampled photoquadrats at AGU-02 and 42% and 58% of the photoquadrats at AGU-03. At AGU-01 in the south region, species of *Halimeda* occurred in only 8% of sampled photoquadrats, but species of *Dictyosphaeria* were abundant and occurred in 33% of sampled photoquadrats. Broad ranges of abundance were observed for both the brown macroalgal genus *Dictyota* and the calcified, red algal genus *Jania*, occurring in 8%–58% and 8%–50% of the photoquadrats sampled at Aguijan, depending on the location of the survey sites. For the majority of the 29 algal species tentatively identified in the field, no distinctive spatial patterns of distribution were observed at Aguijan. However, 5 of the 6 algal genera observed at AGU-01 on the southeastern coast also occurred at both of the other sites surveyed in 2005. The exception, the green algal genus *Microdictyon*, occurred in 50% of photoquatrats sampled at AGU-01 but was not seen elsewhere at this island. The second- and third-most abundant genera at AGU-01 were the chlorophytes *Dictyosphaeria* and *Caulerpa*, occurring in 33% and 58% of sampled photoquadrats, suggesting that conditions on the southeastern shore may favor green algal growth. Species of *Jania* were quite abundant at AGU-02 and AGU-03, occurring in 33% and 50% of sampled photoquadrats. In contrast, at AGU-01, where green algae were dominant, species in this genus were recorded less frequently, occurring in only 8% of sampled photoquadrats.

Turf algae, crustose coralline red algae, and cyanobacteria were all common in 2005, occurring in 100%, 89%, and 61% of photoquadrats sampled at Aguijan. Communities of both turf algae and crustose coralline red algae were prevalent at all survey sites. Cyanobacteria were less abundant, with occurrence values ranging from 100% at AGU-02 down to 33% at AGU-03, the site on the north central coast where green algae were dominant.

During MARAMP 2007, REA benthic surveys were conducted at only 1 site on a forereef habitat at Aguijan: AGU-02 on the northwestern coast. In the field, 4 macroalgal genera (2 red and 2 green), containing at least 4 species, as well as 3 additional algal functional groups—turf algae, crustose coralline red algae, and cyanophytes—were observed. *Halimeda* was the most abundant genus, occurring in 33% of photoquadrats sampled at Aguijan in 2007 (Fig. 6.6.1d, bottom panel). The

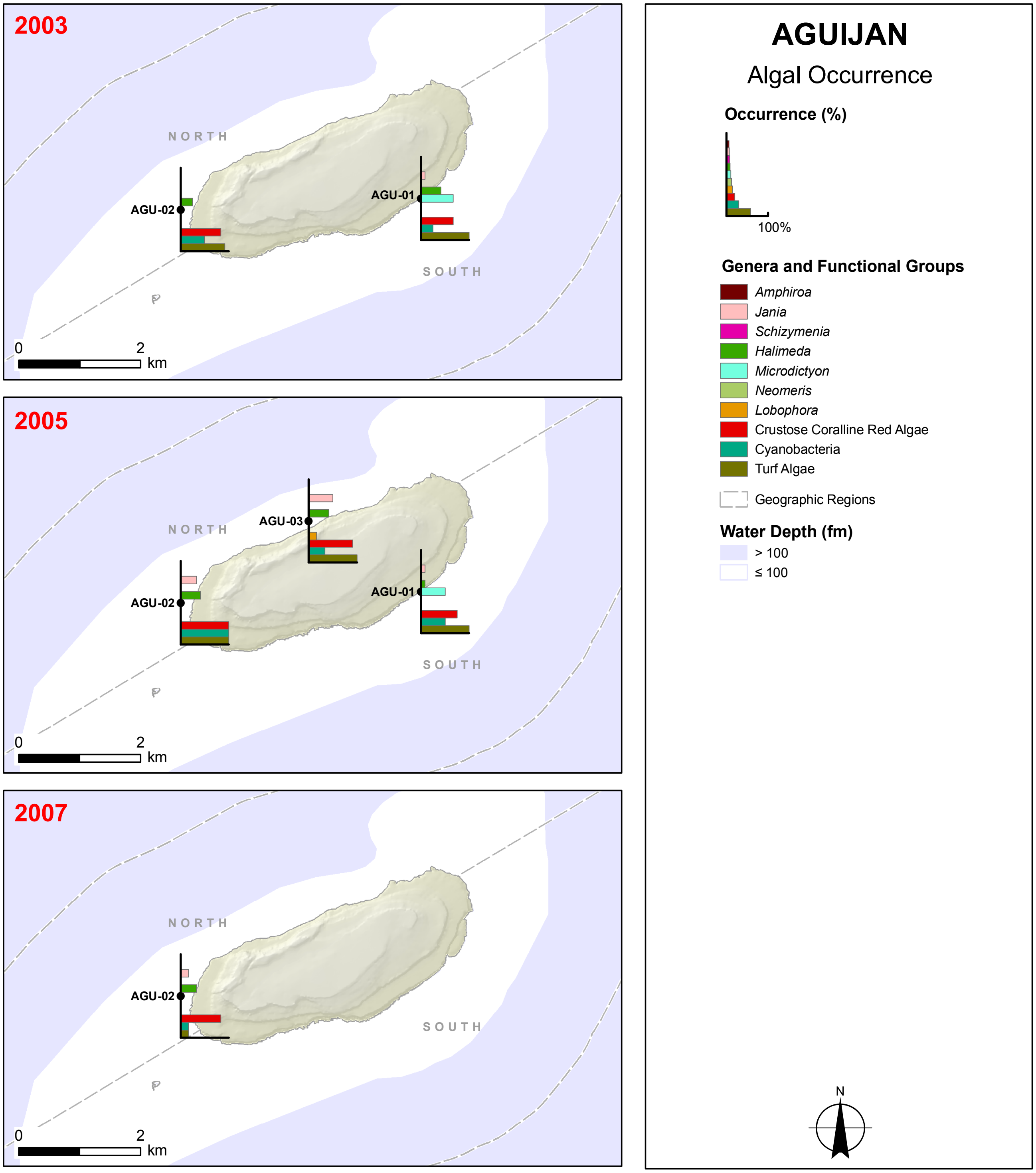


Figure 6.6.1d. Observations of occurrence (%) for select macroalgal genera and algal functional groups from REA benthic surveys on forereef habitats conducted at Aguijan during MARAMP 2003, 2005, and 2007. Occurrence is equivalent to the percentage of photoquadrats in which an algal genus or functional group was observed. The length of the x-axis denotes 100% occurrence.

red algal genera *Jania* and *Portiera*, equally abundant, were recorded in 17% of sampled photoquadrats. The only other genus recorded, *Dictyosphaeria* was found in only 8% of sampled photoquadrats.

Crustose coralline red algae were very common at AGU-02 in 2007, occurring in 83% of sampled photoquadrats. Turf algae and cyanobacteria were equally abundant, occurring in 17% of sampled photoquadrats. Inferences about the spatial distribution of these different functional groups or particular genera are susceptible to error with such a low sampling resolution, and they should be treated with caution.

The number of macroalgal genera recorded on forereef habitats at Aguijan corresponded with the number of sites surveyed within a given MARAMP survey year. The maximum number of distinct genera observed in any given survey year was 12 in 2005, when 3 REA sites were surveyed (for information on data limitations, see hapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”). Between MARAMP 2003 and 2005, a marginal decrease in the diversity of macroalgal genera was observed at AGU-01 on the southeastern coast accompanied by an equivalent increase in generic diversity at AGU-02 on the northwestern shore. With the addition in 2005 of AGU-03, a novel site on the north central coast, the number of unique genera observed at Aguijan increased by 2 to a total of 12. The only site sampled in 2007, AGU-02 had the lowest diversity in 2003 and 2005.

Crustose coralline red algae, recorded in 75%–89% of sampled photoquadrats, were extremely abundant at Aguijan in the 3 MARAMP survey years. However, this dominance was not observed among co-occurring cyanobacterial or turf-algal communities (Fig. 6.6.1d). Cyanobacteria were recorded in 17%–38% of sampled photoquadrats from 2003 to 2007, and the inconsistency in the occurrence of turf algae was more dramatic. Turf algae were encountered in 96% and 100% of the photoquadrats sampled at Aguijan in 2003 and 2005 but present in only 17% of photoquadrats in 2007.

During MARAMP 2003, the green algal genera *Halimeda* and *Microdictyon* were equally abundant, occurring in 33% of photoquadrats sampled at Aguijan. The overall occurrence of *Halimeda* was consistent throughout the 3 survey years (Fig. 6.6.1e). However, a severe reduction in abundance of this genus was observed at AGU-02 from 42% in 2003 to 8% in 2007, while increases in observed abundance occurred at AGU-01 and AGU-03 between 2003 and 2005. The overall occurrence of *Microdictyon* decreased by one-half to 17% in 2005 and then to 0% in 2007. Since AGU-02 was the only site sampled in 2007 and *Microdictyon* had not been observed there in 2003 or 2005, it is not surprising that this genus was not observed in 2007.

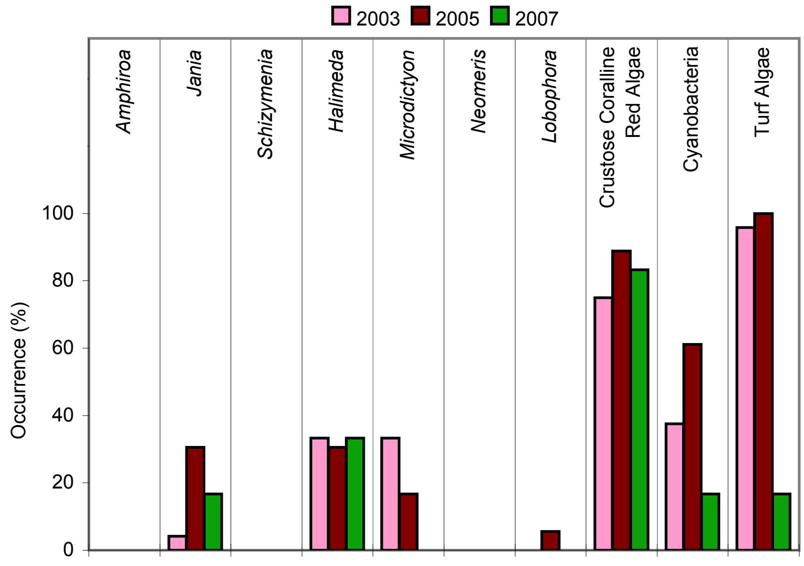


Figure 6.6.1e. Temporal comparison of occurrence (%) values from REA benthic surveys of algal genera and functional groups conducted on forereef habitats at Aguijan during MARAMP 2003, 2005, and 2007.

6.6.2 Surveys for Coralline-algal Disease

During MARAMP 2007, REA benthic surveys for coralline-algal disease were conducted in concert with coral-disease assessments at 1 site on a forereef habitat at Aguijan. At AGU-03, density of disease was 15.4 cases 100 m^{-2} (Fig. 6.6.2a), a high level relative to survey results for other sites in the Marina Archipelago. All cases recorded at this site in the north region corresponded to the coralline lethal orange disease.

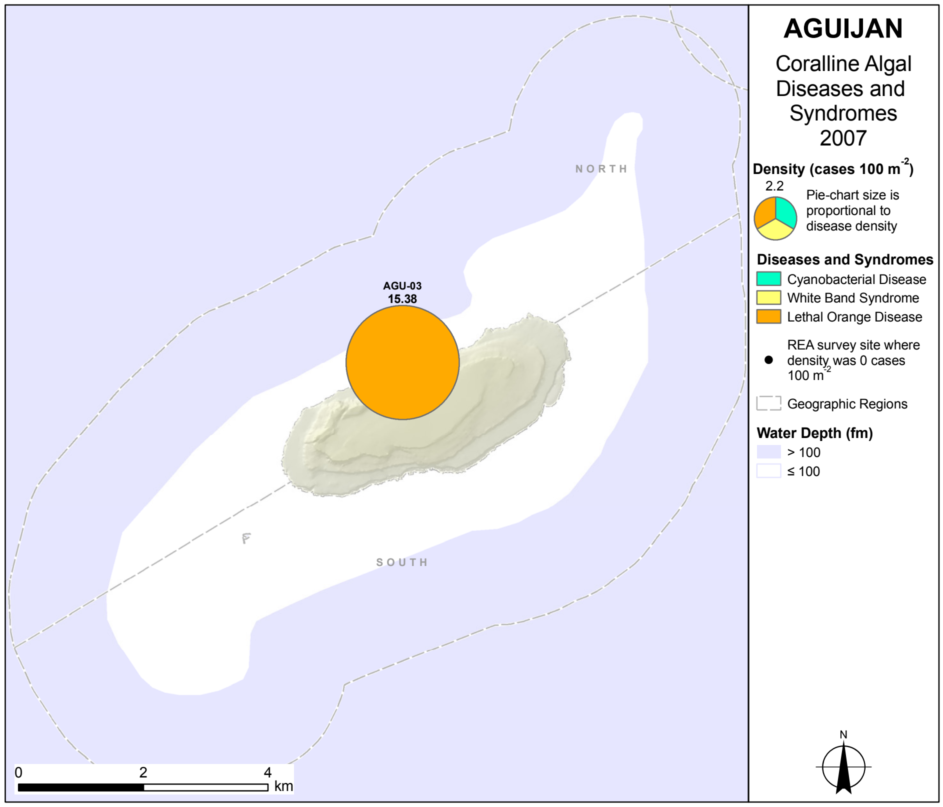


Figure 6.6.2a. Density (cases 100 m^{-2}) of the coralline lethal orange disease found in the REA benthic survey conducted on a forereef habitat at Aguijan during MARAMP 2007.

6.7 Benthic Macroinvertebrates

6.7.1 Benthic Macroinvertebrates Surveys

Four groups of benthic macroinvertebrates—sea urchins, sea cucumbers, giant clams, and the crown-of-thorns seastars (COTS)—were monitored on forereef habitats around the island of Aguijan through REA and towed-diver benthic surveys during MARAMP 2003, 2005, and 2007. This section describes by group the results of these surveys. A list of additional taxa observed during REA invertebrate surveys is provided in Chapter 3: “Archipelagic Comparisons.”

Monitoring these 4 groups of ecologically and economically important taxa provides insight into the population distribution, community structure, and habitats of the coral reef ecosystems of the Mariana Archipelago. High densities of the corallivorous COTS can affect greatly the community structure of reef ecosystems. Giant clams are filter feeders that are sought after in the Indo-Pacific for their meat, which is considered a delicacy, and for their shells. Sea cucumbers, sand-producing detritus foragers, are harvested for food. Sea urchins are important algal grazers and bioeroders.

In 2003, 2 REA surveys and 4 towed-diver benthic surveys were conducted at Aguijan. In 2005, 3 REA surveys and 6 towed-diver benthic surveys were performed around Aguijan. In 2007, because of the lack of an invertebrate scientific diver, no REA surveys were conducted; however, 3 towed-diver benthic surveys were completed. Also, when considering survey results from towed-diver surveys, keep in mind that cryptic or small organisms can be difficult for divers to see, so the density values presented in this report, especially of giant clams and sea urchins, may under-represent the number of individuals present.

Overall, both REA and towed-diver surveys suggested low daytime macroinvertebrate abundance on forereef habitats at Aguijan compared to the rest of the Mariana Archipelago. Minor fluctuations in observed densities between MARAMP survey periods occurred with all target groups. Temporal patterns of islandwide mean macroinvertebrate density around Aguijan—from towed-diver benthic surveys during MARAMP 2003, 2005, and 2007—are shown later in this section (Figs. 7.1b, d, f, and h). Because of differences in survey methodology and in REA survey effort, with 2 surveys in 2003, 3 in 2005, and 0 in 2007, temporal comparisons of REA data are not presented (see Chapter 2: “Methods and Operational Background,” Section 2.4.7: “Benthic Macroinvertebrates”).

Giant Clams

During MARAMP 2003, species of *Tridacna* giant clams were observed at both of the REA sites surveyed and in 3 of the 4 towed-diver surveys conducted at Aguijan (Fig. 6.7.1a, top panel). The sample mean density of giant clams from REA surveys was 4 organisms 100 m^{-2} (SE 1), and the overall mean density from towed-diver surveys was 0.05 organisms 100 m^{-2} (SE 0.01). Survey results suggest that giant clams were most abundant at AGU-02 off the northwest coast with 5 organisms 100 m^{-2}. Among all towed-diver surveys around this island, the survey completed along the northwest coast had the highest mean density of giant clams with 0.15 organisms 100 m^{-2}; segment densities from this survey ranged from 0.03 to 0.39 organisms 100 m^{-2}. The second-greatest mean density of giant clams from a towed-diver survey was 0.05 organisms 100 m^{-2}, recorded around the southwestern shore; segment densities ranged from 0 to 0.18 organisms 100 m^{-2}.

During MARAMP 2005, giant clams were observed at 1 of the 3 REA sites surveyed and in all 6 towed-diver surveys conducted around Aguijan (Fig. 6.7.1a, middle panel). AGU-03 in the north region had a density of 3 organisms 100 m^{-2}, and the islandwide mean density of giant clams from towed-diver surveys was 0.05 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around this island, the survey completed along the northwestern coast had the highest mean density of giant clams with 0.11 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.75 organisms 100 m^{-2}. The second-greatest mean density of giant clams from a towed-diver survey was 0.1 organisms 100 m^{-2}, recorded along the southeastern and south central coast; segment densities ranged from 0 to 0.22 organisms 100 m^{-2}.

During MARAMP 2007, giant clams were observed in all 3 towed-diver surveys conducted at Aguijan (Fig. 6.7.1a, bottom panel) with an overall mean density of 0.06 organisms 100 m^{-2} (SE 0.01). Among all towed-diver surveys around this island, the survey completed along the southern coast had the highest mean density of giant clams with 0.1 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.26 organisms 100 m^{-2}. The second-greatest mean density of giant clams was 0.05 organisms 100 m^{-2}, recorded around the west coast; segment densities ranged from 0 to 0.28 organisms 100 m^{-2}.

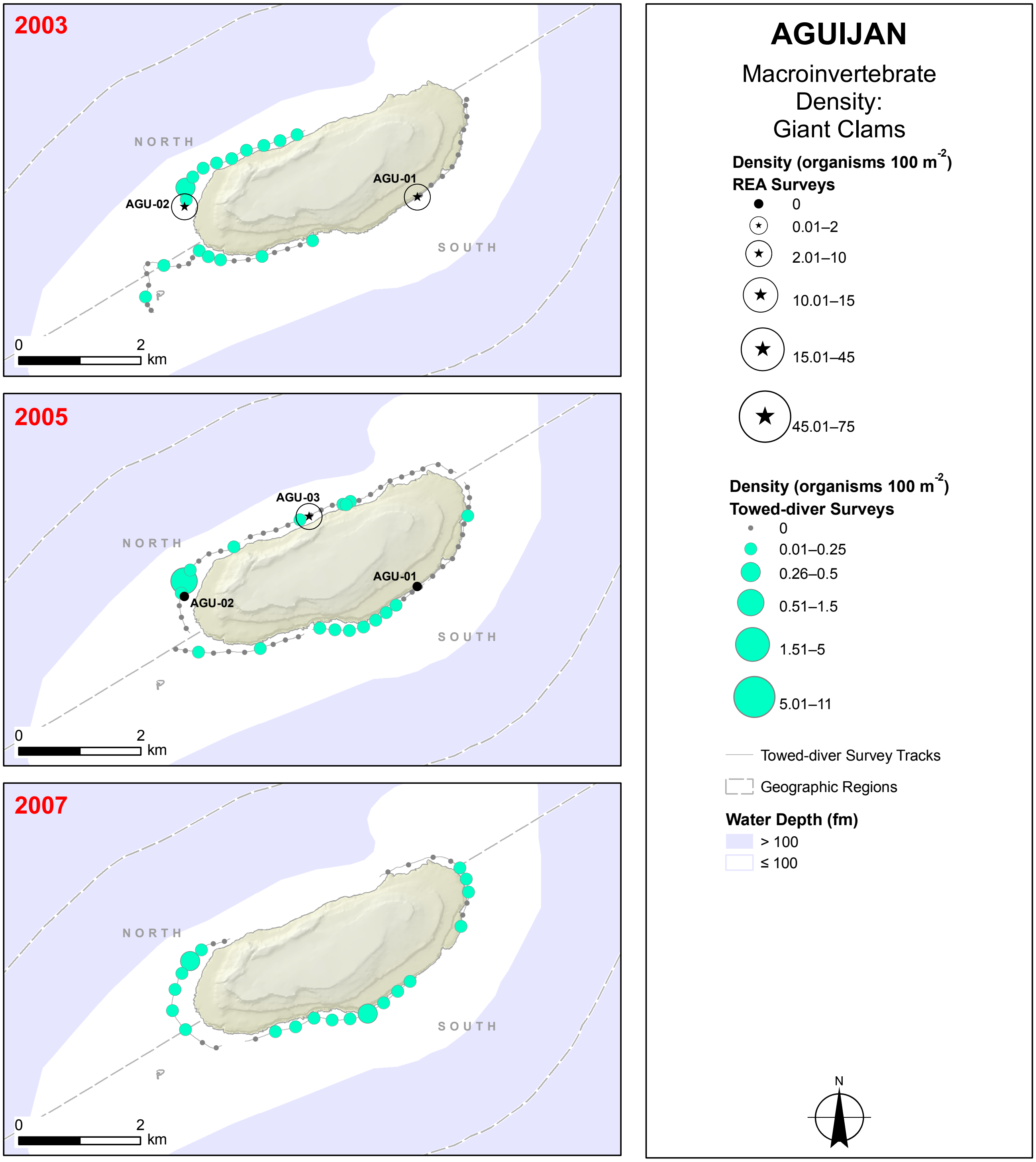


Figure 6.7.1a. Densities (organisms 100 m^{-2}) of giant clams from REA and towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested low abundance of giant clams at Aguijan during the 3 MARAMP survey periods relative to the rest of the Mariana Archipelago (Fig. 6.7.1b). Minor fluctuations in density were observed, but this variation is not necessarily indicative of changes in the population structure of giant clams (for information about data limitations, see Chapter 2: “Methods and Operational Background,” Section 2.4: “Reef Surveys”).

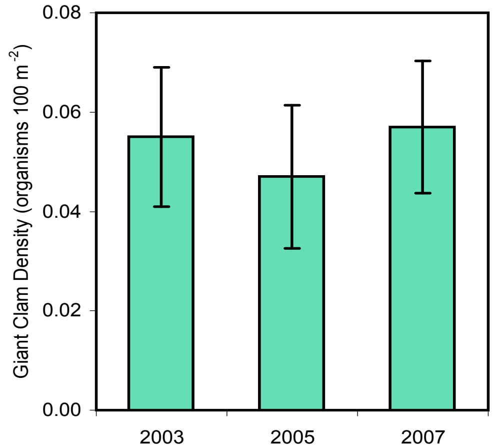


Figure 6.7.1b. Temporal comparison of mean densities (organisms 100 m^{-2}) of giant clams from towed-diver benthic surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Crown-of-thorns Seastars

During MARAMP 2003, no crown-of-thorns seastars (*Acanthaster planci*) were observed at either of the 2 REA sites surveyed at Aguijan, but COTS were recorded in 2 of the 4 towed-diver surveys conducted (Fig. 6.7.1c, top panel). The overall mean density of COTS from towed-diver surveys was 0.06 organisms 100 m^{-2} (SE 0.04). The survey completed along the southwestern coast had the greatest mean density of COTS with 0.17 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 1.49 organisms 100 m^{-2}. The other survey area where COTS were seen, performed along the northwestern coast, recorded a mean density of COTS of 0.08 organisms 100 m^{-2}; segment densities ranged from 0 to 0.29 organisms 100 m^{-2}.

During MARAMP 2005, COTS were observed at 1 of the 3 REA sites surveyed and in 5 of the 6 towed-diver surveys conducted around Aguijan (Fig. 6.7.1c, middle panel). AGU-03 had a COTS density of 3 organisms 100 m^{-2}, and the islandwide mean density of COTS from towed-diver surveys was 0.06 organisms 100 m^{-2} (SE 0.02). The majority of COTS recorded during towed-diver surveys were observed in the north region. Among all towed-diver surveys around this island, the survey completed along the north central coast had the greatest mean density of COTS with 0.20 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.47 organisms 100 m^{-2}. The second-greatest mean density of COTS from a towed-diver survey was 0.11 organisms 100 m^{-2}, recorded along the northwestern coast; segment densities ranged from 0 to 0.50 organisms 100 m^{-2} The survey completed along the northeast coast had a mean density of 0.07 organisms 100 m^{-2}; segment densities ranged from 0 to 0.25 organisms 100 m^{-2}.

During MARAMP 2007, COTS were observed in all 3 towed-diver surveys conducted at Aguijan (Fig. 6.7.1c, bottom panel) with an overall mean density 0.01 organisms 100 m^{-2} (SE 0.004). Among all towed-diver surveys around this island, the survey completed around the west coast had the greatest mean density with 0.03 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 0.07 organisms 100 m^{-2}.

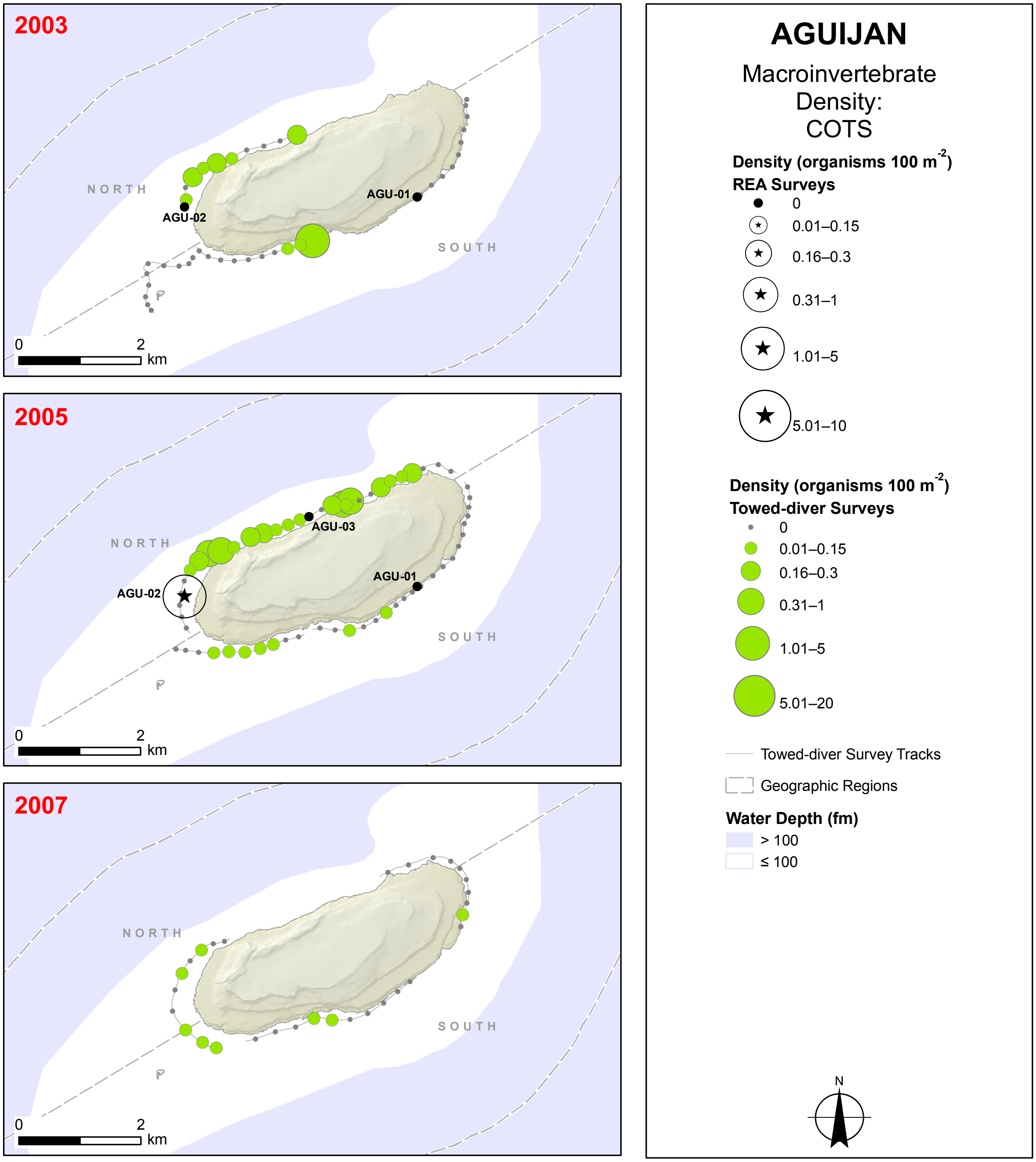


Figure 6.7.1c. Densities (organisms 100 m^{-2}) of COTS from REA and towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested high daytime densities of COTS at Aguijan during MARAMP 2003 and 2005, compared to the rest of the Mariana Archipelago. Overall observed mean values, and particularly results for individual towed-diver surveys, suggested that daytime densities of COTS at Aguijan were higher during MARAMP 2003 and 2005 than during MARAMP 2007 (Fig. 6.7.1d). Given that COTS can decimate a reef, understanding whether their observed densities signify an outbreak is important. By means of a manta-tow technique—which uses snorkel divers as observers in a manner similar to the procedure established for using scuba divers to conduct MARAMP towed-diver surveys—Moran and De'ath (1992) defined a potential outbreak as a reef area where the density of *A. planci* was > 1500 organisms per km² (0.15 organisms 100 m^{-2}) and the level of dead coral present was at least 40%. Using this definition only in terms of COTS density and considering each towed-diver survey as an individual reef area, localized areas with relatively high densities that suggest that they were undergoing an outbreak were found during MARAMP 2003 and 2005. In 2003, a towed-diver survey along the southwestern shore met this criterion with a COTS density of 0.17 organisms 100 m^{-2}, and, in 2005, a survey along the north central coast did so with a density of 0.20 organisms 100 m^{-2}.

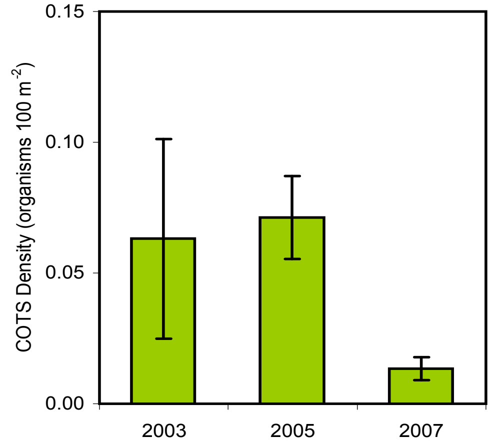


Figure 6.7.1d. Temporal comparison of COTS mean densities (organisms 100 m^{-2}) from towed-diver benthic surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Cucumbers

During MARAMP 2003, no sea cucumbers were observed at either of the 2 REA sites surveyed at Aguijan, but 2 of the 3 towed-diver surveys had recordings of sea cucumbers (Fig. 6.7.1e, top panel), with an overall mean density of 0.32 organisms 100 m^{-2} (SE 0.08). The survey completed southwest of Aguijan at Naftan Rock (for place-names and their locations, see Fig. 6.2a in Section 6.2: "Survey Effort") had the highest mean density of sea cucumbers with 0.81 organisms 100 m^{-2}; segment densities from this survey ranged from 0.05 to 1.76 organisms 100 m^{-2}.

During MARAMP 2005, sea cucumbers were observed at 1 of the 3 REA sites and in 4 of the 6 towed-diver surveys conducted around Aguijan (Fig. 6.7.1e, middle panel). AGU-03 in the north region had a density of 3 organisms 100 m^{-2}, and the islandwide mean density of sea cucumbers from towed-diver surveys was 0.05 organisms 100 m^{-2} (SE 0.01). Of the organisms observed at AGU-03, one was from the genus *Holothuria*, and the others were unknown. Among all towed-diver surveys around this island, the survey completed along the northwestern coast had the highest mean density of sea cucumbers with 0.14 organisms 100 m^{-2}; segment densities from this survey ranged from 0.04 to 0.38 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers from a towed-diver survey was 0.11 organisms 100 m^{-2}, recorded along the southwestern coast; segment densities ranged from 0 to 0.38 organisms 100 m^{-2}.

During MARAMP 2007, sea cucumbers were observed in all 3 towed-diver surveys conducted at Aguijan (Fig. 6.7.1e, bottom panel) with an overall mean density of 2.53 organisms 100 m^{-2} (SE 1.1). Among all towed-diver surveys around this island, the survey completed along the northeastern coast had the highest mean density of sea cucumbers with 7.4 organisms 100 m^{-2}; segment densities from this survey ranged from 0.07 to 24.07 organisms 100 m^{-2}. The second-greatest mean density of sea cucumbers was 0.15 organisms 100 m^{-2}, recorded around the west coast; segment densities ranged from 0.02 to 0.37 organisms 100 m^{-2}.

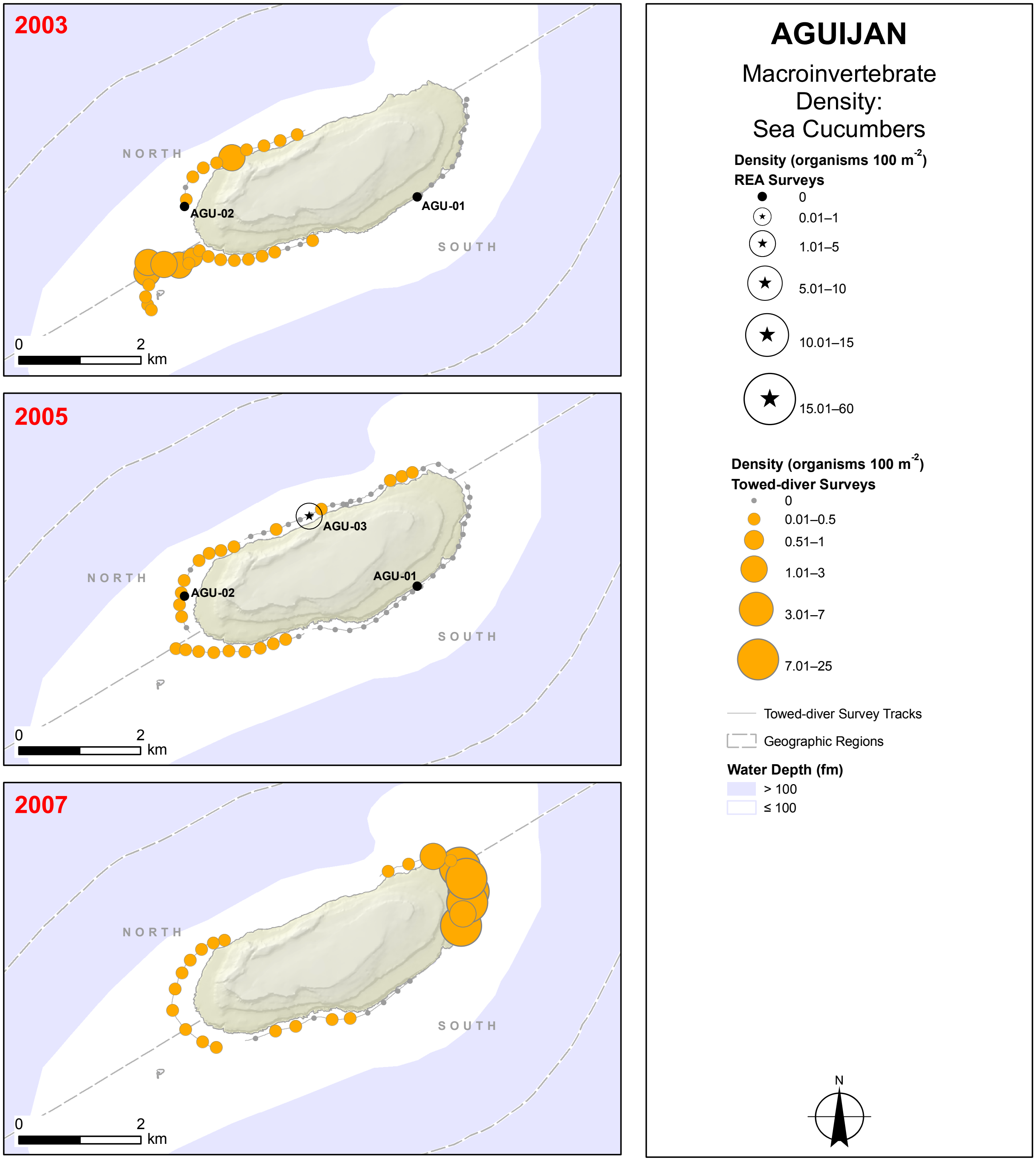


Figure 6.7.1e. Densities (organisms 100 m^{-2}) of sea cucumbers from REA and towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007.

With the exception of an individual towed-diver survey conducted around the northeastern coast of Aguijan during MARAMP 2007, daytime abundance of sea cucumbers was low around Aguijan relative to the rest of the Mariana Archipelago. The overall observed mean density of sea cucumbers around Aguijan was higher in 2007 than in 2003 and 2005 (Fig. 6.7.1f). Survey results suggest that a recruitment event may have occurred along the northeastern shore, since no sea cucumbers were seen there in 2003 and 2005 but in 2007 a mean density of 7.39 organisms 100 m^{-2} was recorded. Minor fluctuations in densities are not necessarily indicative of changes in the population structure of sea cucumbers (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys").

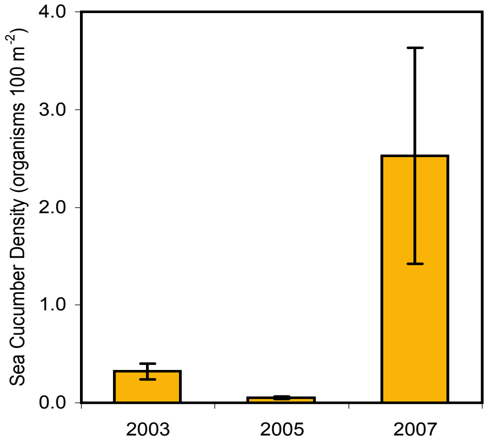


Figure 6.7.1f. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea cucumbers from towed-diver benthic surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Sea Urchins

During MARAMP 2003, sea urchins were observed at both of the REA sites surveyed and in all 4 of the towed-diver surveys conducted at Aguijan (Fig. 6.7.1g, top panel). The sample mean density of sea urchins from REA surveys was 40.5 organisms 100 m^{-2} (SE 4.5), and the overall mean density from towed-diver surveys was 1.77 organisms 100 m^{-2} (SE 0.35). Survey results suggest that sea urchins were most abundant at AGU-01 on the southeastern coast with 45 organisms 100 m^{-2}. During these REA surveys, 3 genera were observed: *Echinostrephus*, *Echinometra*, and *Echinothrix*. The rock-boring urchin *Echinostrephus* was the dominant macroinvertebrate genus at both sites, accounting for 63% of recorded urchins. Among all towed-diver surveys around this island, the survey completed along the northeastern shore had the highest mean density of sea urchins with 3.47 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 7.53 organisms 100 m^{-2}. The second-greatest mean density from a towed-diver survey was very similar with 3.37 organisms 100 m^{-2}, recorded at Naftan Rock; segment densities ranged from 0 to 7.4 organisms 100 m^{-2}.

During MARAMP 2005, sea urchins were observed at 1 of the 3 REA sites surveyed and in all 3 of the towed-diver surveys conducted around Aguijan (Fig 6.7.1g, middle panel). AGU-01 in the south region had a density of 54 organisms 100 m^{-2}, and the islandwide mean density of sea urchins from towed-diver surveys was 5.37 organisms 100 m^{-2} (SE 0.56). Only rock-boring urchins of the genus *Echinostrephus* were observed at AGU-01. Among all towed-diver surveys around this island, the survey completed along the northeastern coast had the highest mean density of sea urchins with 9.12 organisms 100 m^{-2}; segment densities from this survey ranged from 3.47 to 23.48 organisms 100 m^{-2}. The second-greatest mean density of sea urchins from a towed-diver survey was 3.39 organisms 100 m^{-2}, recorded along the south central shore; segment densities ranged from 1.44 to 4.55 organisms 100 m^{-2}.

During MARAMP 2007, sea urchins were observed during all 3 of the towed-diver surveys conducted at Aguijan (Fig. 6.7.1g, bottom panel) with an overall mean density of 0.57 organisms 100 m^{-2} (SE 0.17). Among all towed-diver surveys around this island, the survey completed along the south central coast had the highest mean density of sea urchins with 1.44 organisms 100 m^{-2}; segment densities from this survey ranged from 0 to 3.04 organisms 100 m^{-2}.

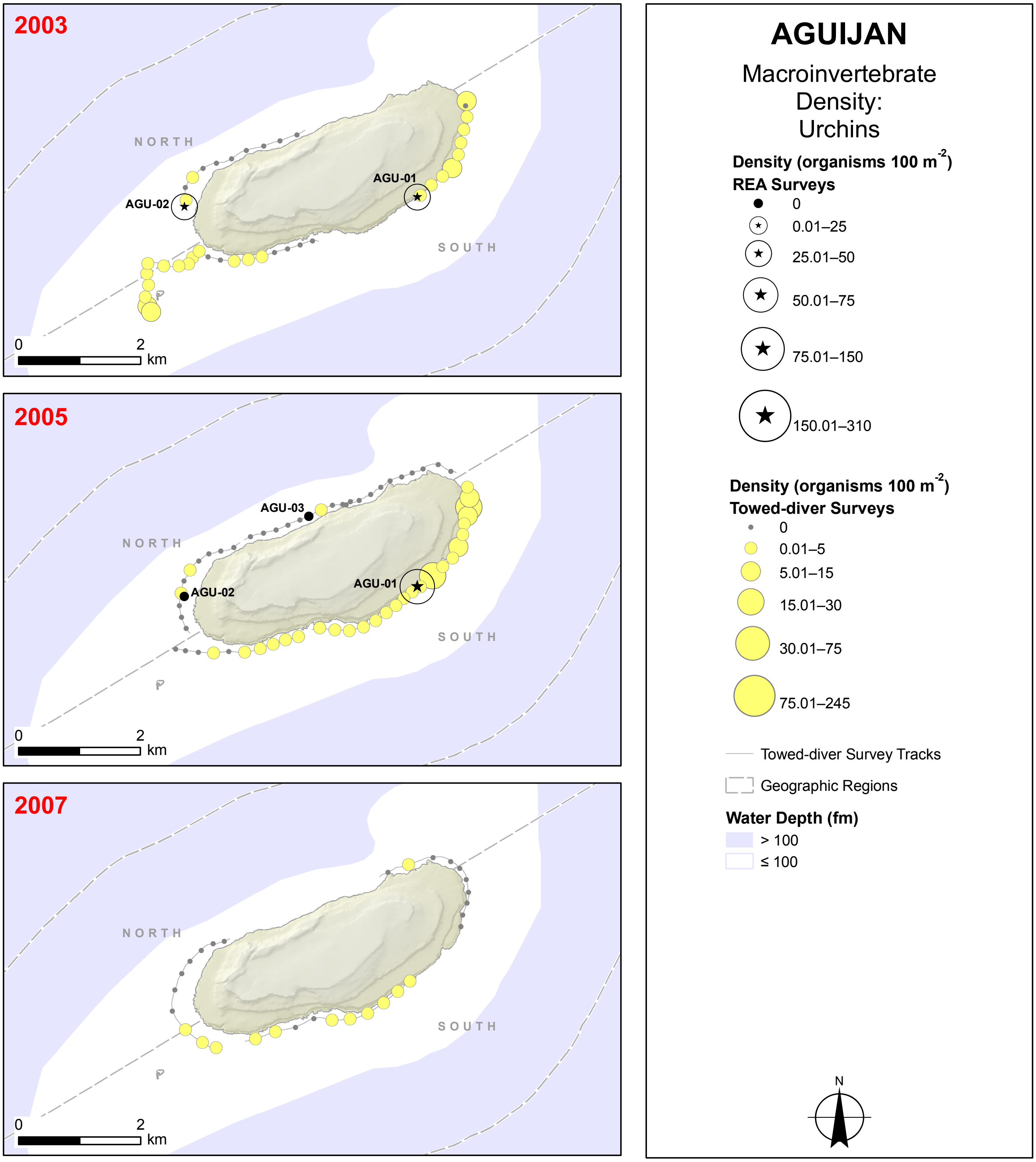


Figure 6.7.1g. Densities (organisms 100 m^{-2}) of sea urchins from REA and towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007.

Towed-diver surveys suggested low daytime abundance of sea urchins around Aguijan during MARAMP 2003, 2005 and 2007, compared to the rest of the Mariana Archipelago. The overall observed mean density of sea urchins around Aguijan was higher in 2003 and 2005 than in 2007 (Fig. 6.7.1h). This variation may be a result of differences between survey years in the number of surveys conducted and other factors and is not necessarily indicative of changes in the population structure of sea urchins (for information about data limitations, see Chapter 2: "Methods and Operational Background," Section 2.4: "Reef Surveys")

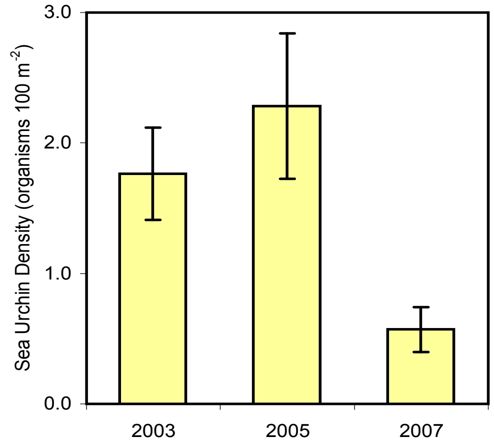


Figure 6.7.1h. Temporal comparison of mean densities (organisms 100 m^{-2}) of sea urchins from towed-diver benthic surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

6.8 Reef Fishes

6.8.1 Reef Fish Surveys

Large-fish Biomass

During MARAMP 2003, 3 towed-diver surveys for large fishes (≥ 50 cm in total length [TL]) were conducted in forereef habitats at the island of Aguijan with a fourth survey completed near Naftan Rock southwest of this island. The overall estimated mean biomass of large fishes at Aguijan, calculated as weight per unit area, was 0.16 kg 100 m^{-2} (SE 0.03), a low value and 7 times less than the archipelago-wide mean biomass of large fishes observed for this survey period. With only 4 surveys conducted, no clear spatial patterns were apparent in the distribution of large-fish biomass (Fig. 6.8.1a, top panel). Reef sharks (Carcharhinidae) and parrotfishes (Scaridae) contributed the largest proportions to overall mean large-fish biomass. Two reef sharks were recorded at Aguijan during in 2003. Both sharks were blacktip reef shark (*Carcharhinus melanopterus*), and both were observed in the south region with 1 on the west side and 1 on the east side.

During MARAMP 2005, 6 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats around Aguijan. The islandwide estimated mean biomass of large fishes was 0.21 kg 100 m^{-2} (SE 0.08), a value similar to the level observed in 2003. Biomass values for large fishes were highest along the northwestern coast, where 2 whitetip reef shark (*Triaenodon obesus*) were observed during a single survey (Fig. 6.8.1a, middle panel). Reef sharks and surgeonfishes (Acanthuridae) contributed the largest proportions to islandwide mean large-fish biomass. Five sharks were observed in total, all of them in the north region.

During MARAMP 2007, 3 towed-diver surveys for large fishes (≥ 50 cm in TL) were conducted in forereef habitats at Aguijan. The overall estimated mean biomass of large fishes at this island was 0.15 kg 100 m^{-2} (SE 0.11), a level similar to results from previous MARAMP survey years (Fig. 6.8.1a, bottom panel). Biomass values for large fishes were highest around the east side of this island. Reef sharks and snappers (Lutjanidae) contributed the largest proportions to overall mean large-fish biomass. Three sharks were observed, all along the southeastern coast.

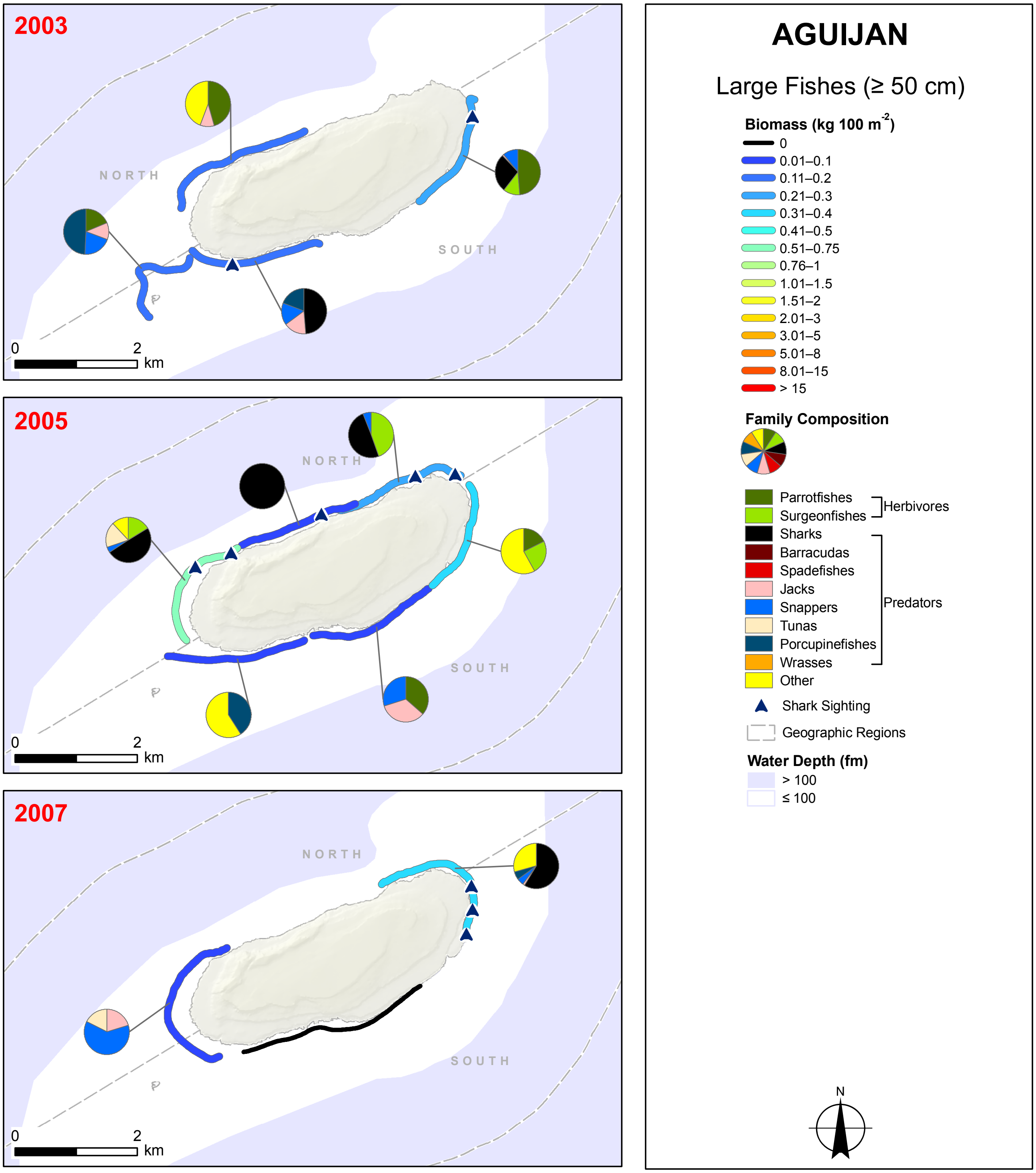


Figure 6.8.1a. Observations of large-fish (≥ 50 cm in TL) biomass (kg 100 m-²), family composition, and individual shark sightings from towed-diver fish surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007. Each blue triangle represents a sighting of one or more sharks recorded inside or outside of the survey area over which it is shown.

Large-fish biomass from towed-diver surveys of forereef habitats was similar across the 3 MARAMP survey years (Fig. 6.8.1b). Temporal comparisons are confounded by the inconsistent survey effort between years. The number of shark sightings recorded was higher in 2005 than in 2003 and 2007: 5 versus 2–3 sightings. For the 3 MARAMP survey periods combined, mean large-fish biomass at Aguijan was 0.17 kg 100 m^{-2} (SE 0.02). Although this level of large-fish biomass is low compared to the archipelago-wide average, this overall mean estimate for Aguijan is similar to values recorded at other southern islands.

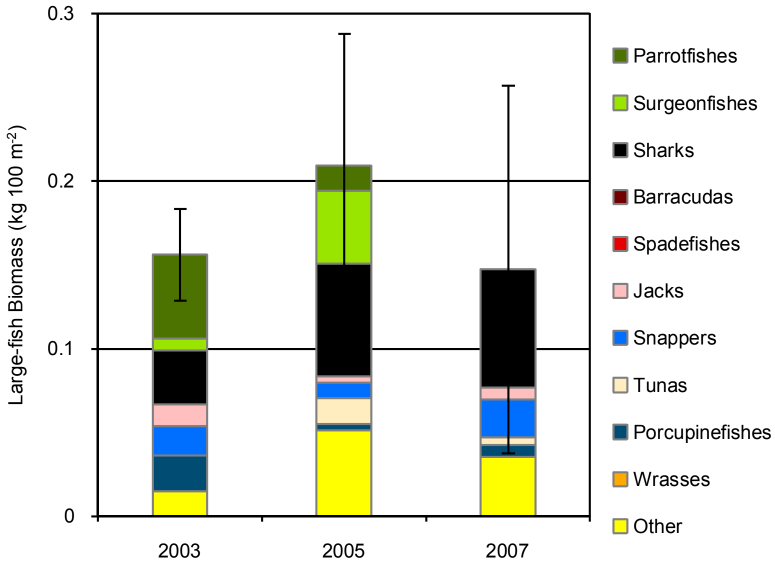


Figure 6.8.1b. Temporal comparison of mean values of large-fish (≥ 50 cm in TL) biomass (kg 100 m^{-2}) from towed-diver fish surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

Total Fish Biomass and Species Richness

Total fish biomass for the 2 REA sites surveyed in forereef habitats at Aguijan during MARAMP 2003 was moderate, compared to other sites in the Mariana Archipelago, with an overall sample mean of 4.69 kg 100 m^{-2} (SE 1.67). Fish biomass was higher at AGU-01 (Fig. 6.8.1c, top panel), mainly because of fusiliers (Caesionidae), herring (Clupeidae), and emperors (*Lethrinus* spp.). Other families commonly observed at AGU-01 were surgeonfishes and triggerfishes (Balistidae). Surgeonfishes accounted for 47% of total fish biomass at AGU-02. Species richness at Aguijan, based on REA surveys conducted during MARAMP 2003, was 34 and 38 species 100 m^{-2} at AGU-01 and AGU-02, values similar to the archipelago-wide mean of 31.1 species 100 m^{-2}.

Total fish biomass for the 3 REA sites surveyed in forereef habitats at Aguijan during MARAMP 2005 was moderate, compared to other sites in the Mariana Archipelago, with an overall sample mean of 6.50 kg 100 m^{-2} (SE 0.73). Surgeonfishes accounted for 35%–56% of the total fish biomass per site (Fig. 6.8.1c, middle panel). Parrotfishes and damselfishes (Pomacentridae) were also common. The most common species was the bullethead parrotfish (*Chlorurus sordidus*).

Based on REA surveys conducted during MARAMP 2005, species richness at Aguijan, with a range of 31–33 species 100 m^{-2}, was high relative to results from other islands in the Marina Archipelago and similar to the diversity seen at this island in 2003. Species observed at Aguijan but rarely seen elsewhere in the Mariana Archipelago included the leopard blenny (*Exallis brevis*), mackerel scad (*Decapterus macarellus*), tomato clownfish (*Amphiprion frenatus*), sixblotch hind (*Cephalopholis sexmaculata*), and bronzespot razorfish (*Iniistius celebicus*).

Total fish biomass during MARAMP 2007 was 4.52 kg 100 m^{-2} at AGU-03, the single REA site surveyed at Aguijan. Surgeonfishes composed about two-thirds of total fish biomass (Fig. 6.8.1c, bottom panel). Species richness at AGU-03, based on REA surveys conducted during MARAMP 2007, was 22 species seen 100 m^{-2}, a value lower than the diversity recorded at Aguijan during previous MARAMP survey years.

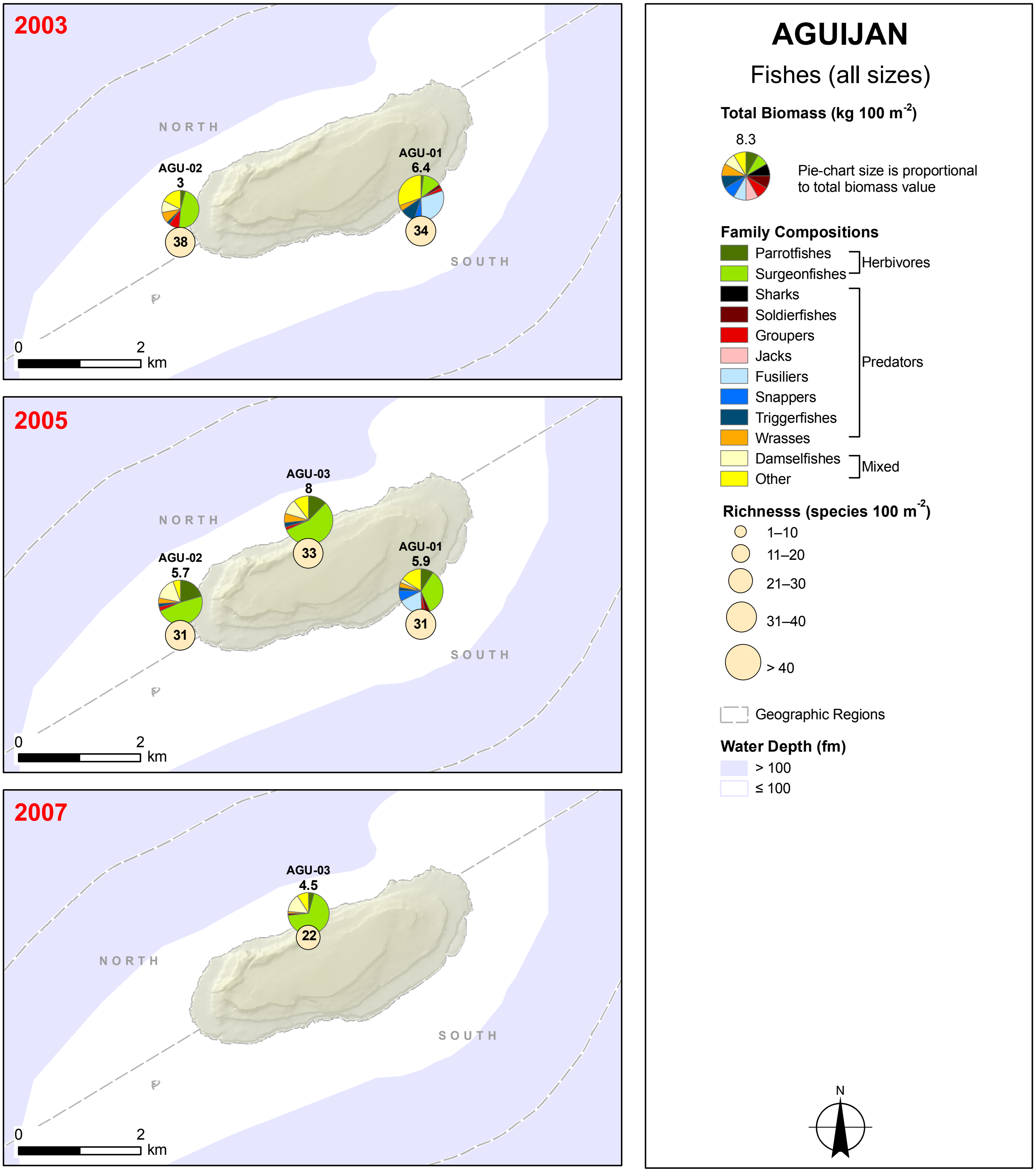


Figure 6.8.1c. Observations of total fish biomass (all species and size classes in kg 100 m^{-2}), family composition, and species richness (species 100 m^{-2}) from REA fish surveys using the belt-transect method in forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007.

Because of this island's small size, only 1–3 REA sites were surveyed at Aguijan during MARAMP 2003, 2005, and 2007. The low number of surveys makes assessing spatial patterns around this island difficult. Nearly half of the total fish biomass recorded at REA sites at Aguijan was composed of surgeonfishes. Estimates of total fish biomass at Aguijan were similar between the 3 MARAMP survey years (Fig. 6.8.1d), with few observations of medium- and large-sized fishes, and slightly higher than the overall mean values of total fish biomass recorded at other islands on the southern end of the Mariana Archipelago.

Overall species richness varied among sites from year to year with no clear spatial or temporal trend in diversity observed. The average fish species richness at Aguijan was 30 species 100 m^{-2} (SE 2) across all REA surveys conducted during MARAMP 2003, 2005, and 2007. Exactly the same as the average observed at Tinian, this level of diversity was moderate for the Mariana Archipelago but 50% higher than the average found around Guam, an unexpected difference given Aguijan's size and homogenous habitat.

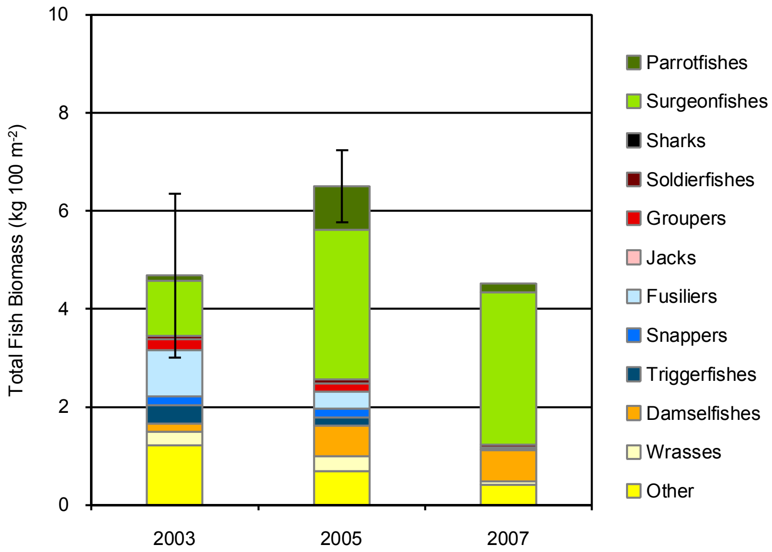


Figure 6.8.1d. Temporal comparison of mean values of total fish biomass (all species and size classes in kg 100 m^{-2}) from REA fish surveys of forereef habitats conducted around Aguijan during MARAMP 2003, 2005, and 2007. Error bars indicate standard error (± 1 SE) of the mean.

6.9 Marine Debris

6.9.1 Marine Debris Surveys

During MARAMP 2003, 2 sightings of derelict fishing gear and 18 sightings of other man-made objects were recorded in the 4 towed-diver surveys conducted on forereef habitats at the island of Aguijan. Off the northwestern coast, 1 fishing line and 1 anchor with a chain were observed (Fig. 6.9.1a, top panel). The remaining sightings were all noted during the single towed-diver survey that occurred off the west coast of Aguijan and at Naftan Rock. One trawl net and 17 unidentified man-made objects were observed during this survey. No munitions or wrecks were identified.

During MARAMP 2005 and 2007, no sightings of marine debris were recorded in the towed-diver surveys conducted on forereef habitats around Aguijan (Fig. 6.9.1a).

Observations of debris are positive identifications, but absence of reports does not imply lack of debris. Since methods for observing marine debris varied between MARAMP surveys in 2003, 2005, and 2007, temporal comparisons are not appropriate. Debris sightings were recorded differently—with sightings in 2003 recorded as a direct part of diver observational methods and sightings in 2005 and 2007 recorded solely as incidental observations by the towed divers in their observer comments. Still, in both 2005 and 2007, no marine debris was observed.

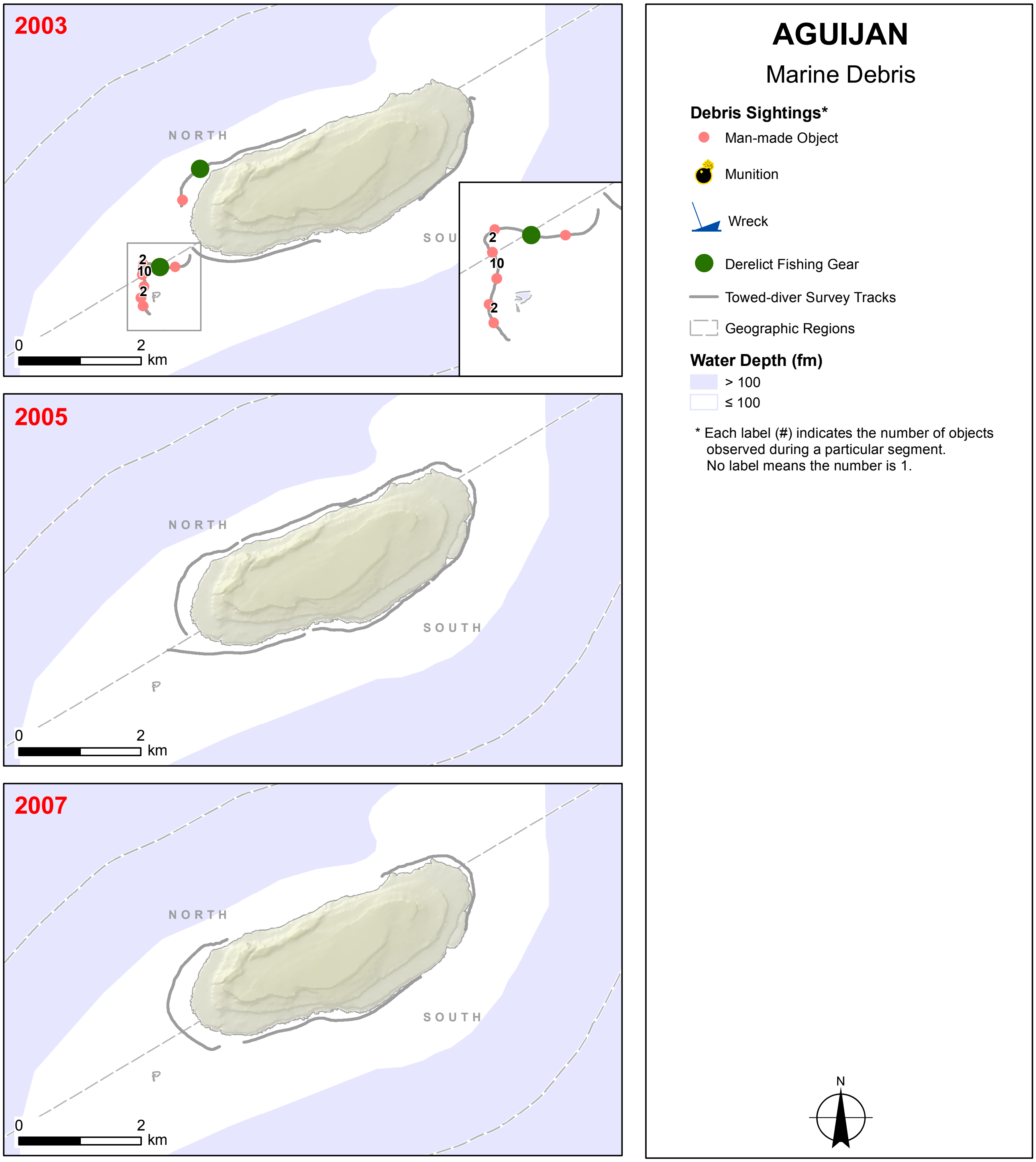


Figure 6.9.1a. Qualitative observations of marine debris from towed-diver benthic surveys of forereef habitats conducted around Aguijan during MARAMP 2003. No debris sightings were recorded in 2005 and 2007. Symbols indicate the presence of specific debris types.

6.10 Ecosystem Integration

The spatial distributions and temporal patterns of individual coral reef ecosystem components around the island of Aguijan are discussed in the discipline-specific sections of this chapter. In this section, key ecological and environmental aspects are considered concurrently to identify potential relationships between various ecosystem components. Few conclusions can be drawn from the sparse data collected at this small island; however, if data describing individual reef components are considered in tandem, some patterns are revealed. The predominant pattern is the difference between benthic communities north and south of Aguijan. In addition to this island-level analysis, evaluations across the entire Mariana Archipelago are presented in Chapter 3: "Archipelagic Comparisons," including archipelago-wide reef condition indices with ranks for Aguijan as well as the other 13 islands covered in this report.

Aguijan is the smallest of the southern islands in the Mariana Archipelago. It is low-lying and flat-topped, formed of a series of carbonate terraces overlying a volcanic core. Located only 9 km southwest of Tinian, Aguijan is surrounded by a sloping bank that descends to ~ 400 m within ~ 2 km of the coast (Fig. 6.3.1a in Section 6.3.1: "Acoustic Mapping"). The limited coverage of multibeam mapping at shallow depths leaves the nature of the nearshore submarine topography unknown. This island is currently uninhabited, partly as a result of the steep onshore slopes and lack of viable land areas.

The highest cover of live hard corals was observed along the northwestern coast (Fig. 6.10a), in an area of spur-and-groove habitat (Fig. 6.10b). This reef area had the highest live coral cover recorded during towed-diver surveys in both 2003 and 2005 with an estimated mean cover of ~ 34%, within a range of 5.1%—62.5% (Fig. 6.5.1a in Section 6.5.1: "Coral Surveys"). Live coral cover in this area and overall at Aguijan was lower in 2007 than in previous MARAMP survey years. Based on towed-diver surveys, estimated cover of live corals was lower on the reef pavement flats observed south of Aguijan than on the habitats surveyed north of this island (Figs. 6.10a and c).

Results from fine-scale REA surveys conducted at Aguijan suggest that coral-colony density at Aguijan was higher at REA sites AGU-02 and AGU-03 in the north region than at AGU-01 in the south region (Fig. 6.5.1b in Section 6.5.1: "Coral Surveys" and Fig. 6.10a). Habitat complexity, estimated during towed-diver surveys, was also higher north of Aguijan compared to the south (Fig. 6.3.3a in Section 6.3.3: "Habitat Characterization"). The highest habitat complexity was observed off the north central coast, in an area characterized by high (20%–75%) cover of crustose coralline algae in both 2003 and 2005. In contrast to the higher cover of live corals and crustose coralline red algae, estimates of macroalgal cover were lower along the northern shores than off the southern coast, with values typically < 30% during each of the 3 MARAMP survey years (Fig. 6.6.1a in Section 6.6.1: "Algal Surveys"). The highest levels of macroalgal cover were observed on the southeastern shore, along the most exposed coast of this island.

Overall, the coral reef ecosystems observed during MARAMP surveys appear to be comparable to the ecosystems surveyed at the other southern islands of Guam, Rota, Tinian, and Saipan, with similar relative cover of live corals, macroalgae, and crustose coralline red algae and similar coral generic richness. No specific spatial pattern in distribution of biomass of large (≥ 50 cm TL) fishes was observed (Fig. 6.8.1a in Section 6.8.1: "Reef Fish Surveys"), and fish biomass estimates for Aguijan were similar to survey results for the other southern islands.

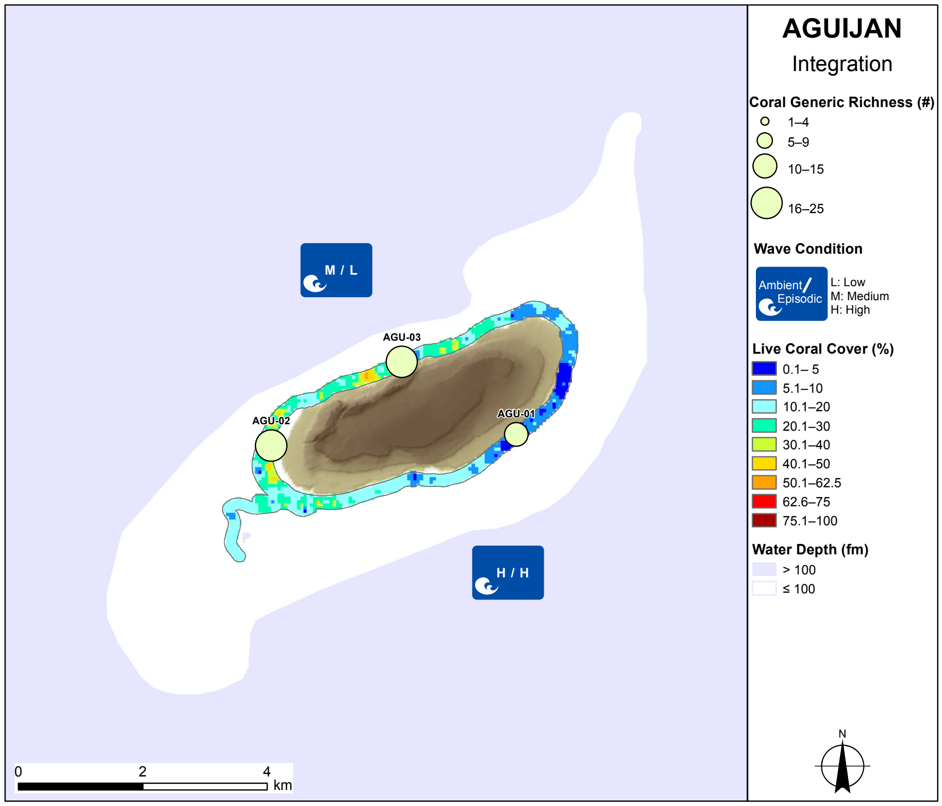


Figure 6.10a. Observations of cover (%) of live hard corals from towed-diver surveys and generic richness from REA surveys conducted on forereef habitats around Aguijan during MARAMP 2003, 2005, and 2007. Values of coral cover represent interpolated values from the 3 MARAMP survey years, and values of coral generic richness represent averages of data from the 3 survey years. A large, blue icon indicates the level of ambient and episodic wave exposure for each geographic region.

Figure 6.10b. Northern reef of Aguijan with spur-and-groove habitat. *NOAA photo by Edmund Coccagna*

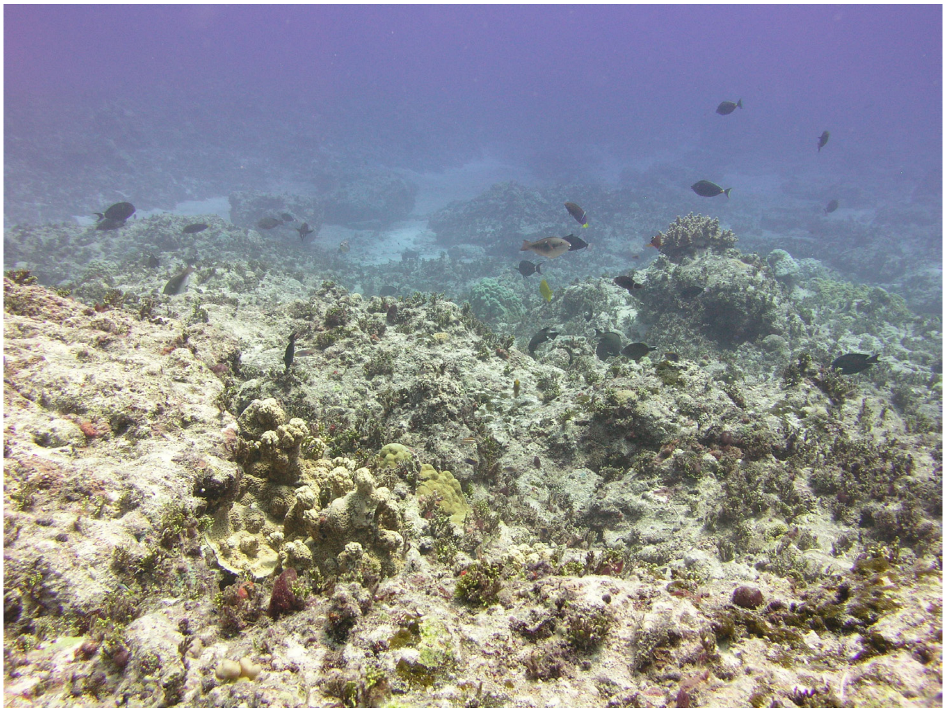


Figure 6.10c. Pavement reef south of Aguijan. *NOAA photo by Robert Schroeder*

6.11 Summary

MARAMP integrated ecosystem observations provide a broad range of information: bathymetry and geomorphology, oceanography and water quality, and biological observations of corals, algae, fishes, and benthic macroinvertebrates along the forereef habitats around the island of Aguijan. Methodologies and their limitations are discussed in detail in Chapter 2: "Methods and Operational Background," and specific limitations of the data or analyses presented in this Aguijan chapter are included in the appropriate discipline sections. Methods information and technique constraints should be considered when evaluating the usefulness and validity of the data and analyses in this chapter. The conditions of the fish and benthic communities and the overall ecosystem around Aguijan, relative to all the other islands in the Mariana Archipelago, are discussed in Chapter 3: "Archipelagic Comparisons."

This section presents an overview of the status of coral reef ecosystems around Aguijan as well as some of the key natural processes and anthropogenic activities influencing these ecosystems:

- Aguijan, with a land area of 7.3 km^2, is the smallest island in the southern portion of the Mariana Archipelago.
- Aguijan has been uninhabited since 1945, but because of its proximity to Tinian, it is still visited by hunting parties.
- Surrounded by steep sea-cliffs, this low-lying island is composed of a series of uplifted, carbonate terraces overlying an older volcanic structure.
- Offshore, Aguijan is surrounded by a sloping bank, the flanks of which descend to a depth of 400 m within ~ 2 km of the coast. It is connected to Tinian by a broad, submerged ridge at a depth of ~ 380 m.
- An east–west gradient was observed in the distribution of sand cover estimated from towed-diver surveys, with the west having more sand than the east, especially in a survey area on the southwestern coast. The seabed in this area was characterized as sand with patch reefs.
- Wave model output shows ambient trade wind swells impacting the south, and to a lesser extent, the north. Episodic wave energy from storm tracks impact the south.
- Water clarity was relatively high (93.4%–97.1%) at Aguijan during MARAMP 2005 and 2007, suggesting that terrestrial runoff is low in the vicinity of Aguijan.

- STR data show that temperatures during September 2006 reached and surpassed the coral bleaching threshold, which is defined as 1˚C above the monthly maximum climatological mean.

- Estimates of live coral cover from towed-diver surveys were congruent with the mean of 7.8% at AGU-03, the only REA site surveyed in 2007, the only year in which coral cover was assessed using the line-point-intercept method. Overall mean coral cover from towed-diver surveys was 12% in 2007, a lower value than the overall means from previous MARAMP survey years. Observed densities of coral colonies from REA surveys were higher along the northern coast of Aguijan than along the southern shore.

- Overall prevalence of coral disease was 0.46% at AGU-03, the only site surveyed for coral disease in 2007. Two types of coral disease were observed: white syndrome (0.31%) and cyanophyte infection (0.15%). Surveys for coralline-algal disease at AGU-03 found cases of coralline lethal orange disease.

- The overall mean cover of crustose coralline red algae essentially remained the same between the 3 MARAMP survey years.

- Estimated biomass of large fishes at Aguijan, based on towed-diver surveys, was comparable to results from other southern islands of the Mariana Archipelago, such as Guam and Tinian. Sharks were seen in each of the 3 MARAMP survey years.

- The average fish species richness at Aguijan was 30 species 100 m^{-2} across all REA surveys conducted during MARAMP 2003, 2005, and 2007. The same estimate made at Tinian, this level of diversity was moderate for the Mariana Archipelago but 50% higher than the average observed at Guam, an unexpected difference given Aguijan's size and homogenous habitat. Nearly half of the total fish biomass recorded at REA sites around Aguijan was composed of surgeonfishes.

- COTS densities were high in 2003 and 2005, compared to the rest of the Mariana Archipelago, with a localized area of high density suggesting that an outbreak was underway observed on the southwestern coast in 2003 and on the north central coast in 2005.

- With the exception of the northeastern shore in 2007, densities of sea cucumbers were low at Aguijan relative to the rest of the Mariana Archipelago. The overall observed densities of giant clams and sea urchins were low at Aguijan in each of the 3 MARAMP survey years.